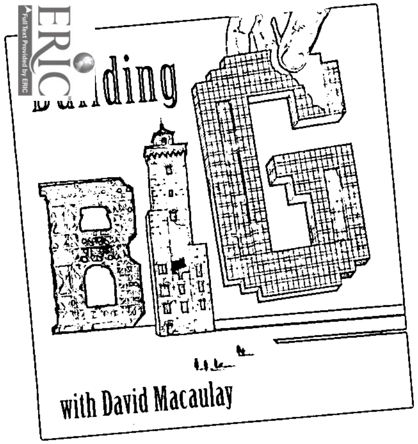
DOCUMENT RESUME

ED 448 062 SE 064 362

AUTHOR	Sammons, James; Sammons, Fran Lyons; Curtis, Paul
TITLE	Building Big with David Macaulay. Activity Guide.
INSTITUTION	WGBH-TV, Boston, MA.
SPONS AGENCY	National Science Foundation, Arlington, VA.
PUB DATE	2000-00-00
NOTE	89p.
AVAILABLE FROM	WGBH, 125 Western Avenue, Boston, MA 02134. E-mail: wgbh materials request@wgbh.org.
PUB TYPE	Guides - Classroom - Teacher (052)
EDRS PRICE	MF01/PC04 Plus Postage.
DESCRIPTORS	*Hands on Science; *Inquiry; Intermediate Grades; Junior High Schools; Mechanics (Physics); *Physical Sciences; Physics; *Science Activities; Science Instruction
IDENTIFIERS	Bridges (Structures)

ABSTRACT

This activity guide is designed for educators and features suggestions for possible activity paths for different amounts of available time and survival tips for activity leaders. Each activity is divided into two sections--educator ideas and activity handouts. Activity sections include: (1) Foundations; (2) Bridges; (3) Domes; (4) Skyscrapers; (5) Dams; (6) Tunnels; and (7) Building Challenges. (YDS)



Activity Guide

Geodesic Dome, page 26

Suspension Bridge, page 24

National Science Foundation
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Dear Educator,

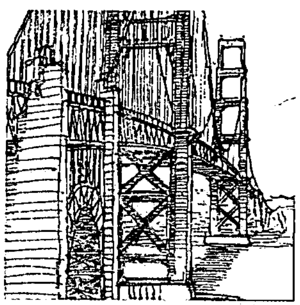
The National Science Foundation is proud to be a major supporter of *Building Big*, the exciting new television series celebrating the built environment and the people behind it. Very few of us who are not engineers understand the vital role that civil engineering plays in our world today. Bridges, tunnels, skyscrapers, domes, dams, and other structures—the visible products of the science of civil engineering—have changed the way we interact with our environment. These structures are daily reminders of the importance of science and mathematics in making our lives safer and more comfortable.

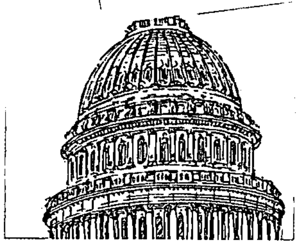
The *Building Big* television series and its exceptional outreach materials (including this guide) invite audiences to experience the challenges and excitement of building on a large scale. It is my hope that children and their families will view civil engineering with a new understanding and affection as a result of this series and the materials that accompany it.

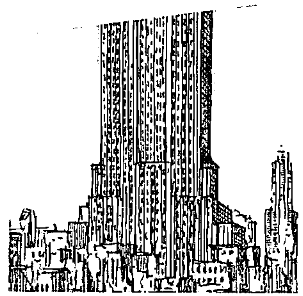
The National Science Foundation is dedicated to promoting a better understanding of science for everyone, and to encouraging young people to pursue careers in science. *Building Big* is a fine addition to our efforts toward those goals. I welcome you to the construction crew and hope that you enjoy the adventure.

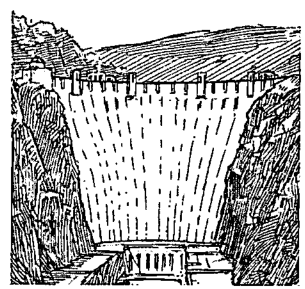
Hyman Field

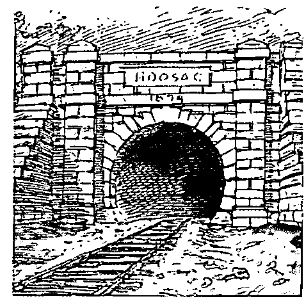
Hyman Field
Senior Advisor for Public Understanding of Research
National Science Foundation











Contents

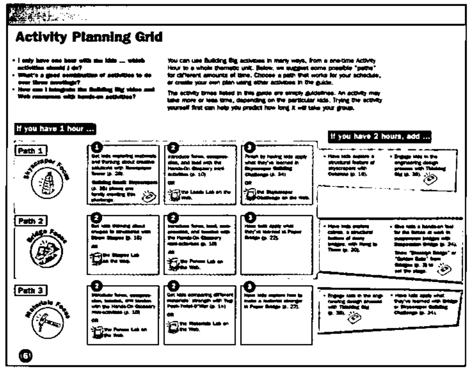
›w to Use This Guide

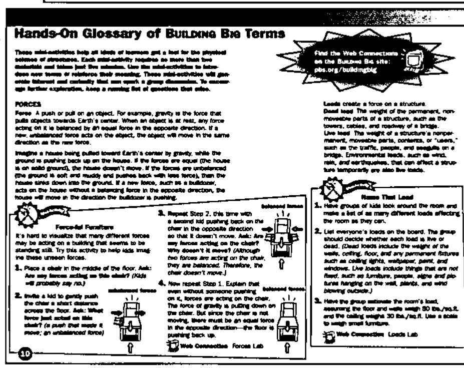
The BUILDING BIG Activity Guide presents a flexible collection of fun, simple hands-on activities for fifth- to eighth-graders. You can use one or two activities or all of them to introduce kids to the basic physical science of large structures and the excitement of inquiry learning.

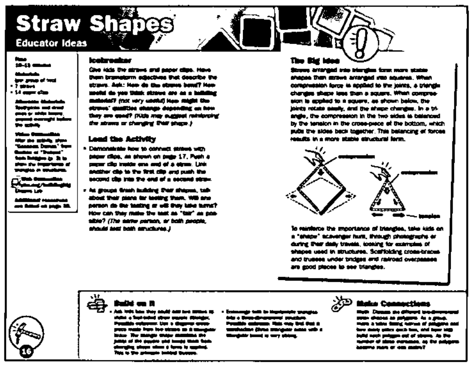
Leading the Activities

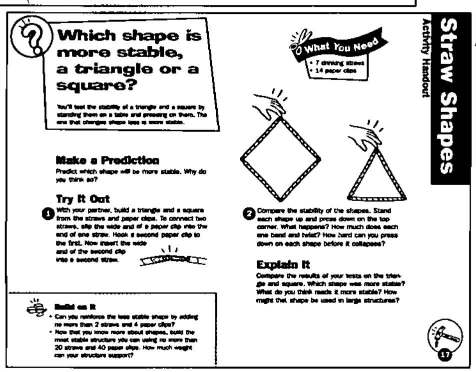
This guide supports you whether you work in an after-school program, classroom, science museum, or other setting; and whether you have very little or a lot of science background and experience with kids.

- The **Activity Planning Grid** (pp. 6–7) suggests ways to incorporate BUILDING BIG activities into your schedule, whether you have one hour or six weeks.
- The **Hands-On Glossary** (pp. 10–13) provides mini-activities that give kids a physical understanding of some basic terms. Use these mini-activities to introduce other activities and to clarify concepts.









- Each hands-on activity (pp. 14–35) consists of an **Educator Ideas** page and a reproducible **Activity Handout.** Read the Activity Handout first to get a sense of the activity. Then read the Educator Ideas page for everything you need to know to lead the activity: time, materials, preparation, icebreaker suggestions, content background, questioning strategies, and follow-up activities.
- The reproducible **Engineer's Notebook** handout (p. 5) provides an organized format for kids to record their predictions, data, observations, and explanations. Have kids collect their completed Engineer's Notebook pages in a portfolio. Use the pages to
  - assess kids' learning;
  - create a bulletin board; or
  - compile a newsletter for families.

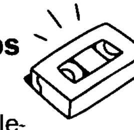
The BUILDING BIG Web Site pbs.org/buildingbig

The Web site offers engaging content and activities that build awareness of civil engineering and enable visitors to explore the physical science of large structures. The **Educator Ideas** pages suggest links to the Web site for each activity. Site highlights include

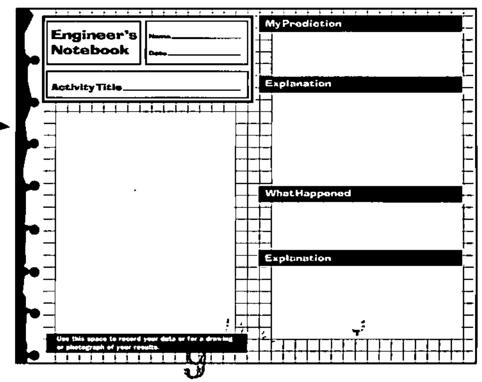
- interactive labs that give users a virtual "hands-on" experience with shapes, materials, forces, and loads;
- interactive building challenges in which users solve problems as they virtually "build" large structures;
- overviews of each type of structure;
- a searchable databank of engineering "Wonders of the World"; and
- interviews with a diverse assortment of engineers.

After working with an engineer to research a structure in their community, kids can write up their own **Local Wonder** and submit it to the site (pp. 36–37.)

Incorporating the BUILDING BIG Videos

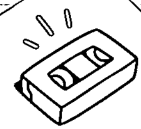


This guide is designed to stand alone—the activities do not require watching the television programs. However, the videos can greatly enhance learning by clearly illustrating science concepts in action and presenting the engaging stories of large-scale building projects and the people behind them. The **Educator Ideas** pages suggest appropriate video segments for each hands-on activity.



Program Descriptions

How does a dam withstand the crushing pressure of a lakeful of water? How does a suspension bridge resist the forces of wind and traffic? Why can we walk in the shadows of mammoth skyscrapers, drive through tunnels deep underground, and sit beneath soaring stadium domes, confident that these giant structures will not collapse? Find out in BUILDING BIG, a new five-part miniseries on megastructures from PBS. Hosted by David Macaulay, award-winning author-illustrator of *The Way Things Work*, each one-hour program focuses on a different type of structure: bridges, domes, skyscrapers, dams, and tunnels. Check your local listings for exact broadcast times.



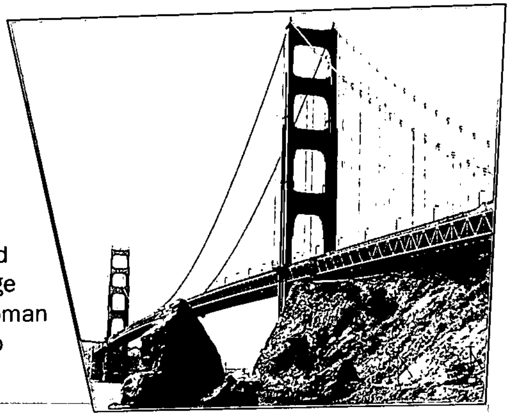
Set your VCRs! One-year off-air taping rights for educators.

(For information on purchasing the videos, see page 38.)

Bridges

Tuesday, October 3 at 8 PM

Some of the most familiar and awe-inspiring large structures are bridges, vital to modern civilization in their ability to connect people and places. The program traces the history of bridge building, from the stone arch bridges of the Roman Empire to Japan's giant, all-steel Akashi-Kaikyo suspension bridge.



Segment	Start*	End**	Length*
Introduction	"Just north of Edinburgh stands Scotland's Firth of Forth bridge..."	"Tonight we begin with bridges."	2:42
Roman Bridges: stone vs. wood; arches	(2:42) Golden Gate bridge	"...for centuries bridge-builders looked for practical alternatives."	5:44
Iron Bridges: cast iron; Dee Bridge failure	(8:26) Stone bridges	"... wrought iron and steel could withstand tension forces very well."	5:59
Trusses: wrought iron; wind loads; open trusses; cantilevers	(14:25) Red train truss	"... engineers had developed a more practical solution for long spans ... and just in time."	5:21
Brooklyn Bridge: suspension bridges; Roebling family; caissons	(19:46) Old New York	"... the confidence to undertake the most difficult bridge project ever attempted."	14:28
Golden Gate: problem-solving; cables; worker safety	(34:14) Sailboat	"... an old nemesis that caught the world's best engineers completely by surprise."	11:50
Environmental Loads: wind load; Tacoma Narrows failure; earthquake loads	(46:04) Ribbon cutting	"... to connect the people of the world for the continued advancement of all civilization."	6:52

Domes

Tuesday, October 10 at 8 PM

More than just big roofs over big spaces, domes symbolize power, prestige, and majesty. The program explores the history of domes, from Emperor Hadrian's Pantheon to the geodesic structures of Buckminster Fuller, and the science principles that support them.

Segment	Start*	End**	Length*
Introduction	"Deep in the heart of Texas, old habits die hard."	"Domes, coming next on Building Big."	2:49
Astrodome: problem-solving; dome vs. flat roof	(2:49) Baseball player swinging	"... how the role of the dome has changed over time."	7:20
Pantheon: symbolism; forces in domes and arches; problem-solving	(10:09) Doors opening into Pantheon	"... nothing to fear in the human world."	7:30
Islamic Domes: symbolism; problem-solving; pendentives	(17:39) Pantheon doors closing	"... the most dramatic dome the world had ever seen."	9:03
St. Peter's: problem-solving; symbolism; tension rings	(26:42) Rome at dawn	"Building new, huge domes would require a radical new approach."	5:57
U.S. Capitol: problem-solving; symbolism; materials	(32:39) U.S. Capitol	"... would change the face of the urban world."	7:54
Geodesic Domes: Buckminster Fuller; materials; triangles; tensegrity	(40:33) City street	"... into the dome of the sky."	12:22

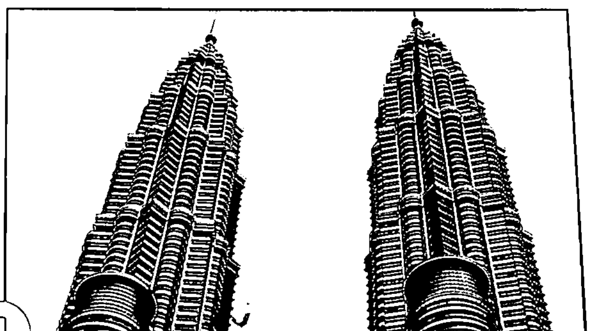
* **Start times and lengths of video segments are written as minutes:seconds.**
** **Script as of press time. Final broadcast version may reflect some differences.**

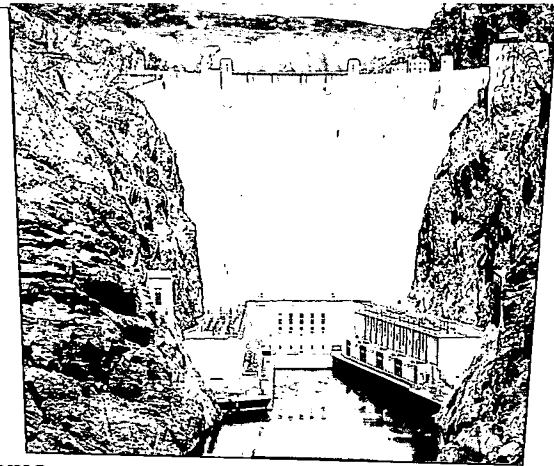
Skyscrapers

Tuesday, October 17 at 8 PM

At 1,476 feet, the Petronas Towers in Malaysia are the world's tallest structures—for now. From Italy's medieval towers to New York's forest of skyscrapers, the program examines the psychology and physics behind skyscrapers.

Segment	Start*	End**	Length*
Introduction	"In the summer of 1929, war broke out on the island of Manhattan."	"Skyscrapers, coming next on Building Big."	Approx. 3:30
San Gimignano: walls and foundations; symbolism	(3:30) Stone towers	"... the world's most picturesque skylines."	Approx. 5:00
Gothic Cathedrals: symbolism; tools; problem-solving; flying buttresses	(8:30) Cathedral	"And once more, France would take center stage."	Approx. 5:30
Eiffel Tower: Gustave Eiffel; iron; problem-solving; elevators	(14:00) Exposition poster	"... making Eiffel a wealthy man."	Approx. 4:00
Chicago: problem-solving; metal frames; columns and beams	(18:00) Chicago lakefront	"... the metal frame could go much, much higher."	Approx. 6:30
Empire State Building: problem-solving; efficiency; plane crash	(24:30) New York skyline	"... skyscrapers might have reached their limits."	Approx. 7:30
Wind Load: glass; tube frame; Citicorp building near-disaster; tuned-mass damper; tradeoffs	(32:00) Lunch counter	"... no longer just an American obsession."	Approx. 13:00
Petronas Towers: symbolism; problem-solving; wind load; tradeoffs	(45:00) Petronas Towers	"... to use what tools we have. We've always done that."	Approx. 7:00





Dams

Tuesday, October 24 at 8 PM

Dams may be the most controversial of large structures. While dams can store water, prevent floods, and generate electricity, they can also displace entire towns and damage the environment. The program explores the engineering challenges and social impact of big dams, including the concrete Hoover Dam and Egypt's enormous Aswan High Dam.

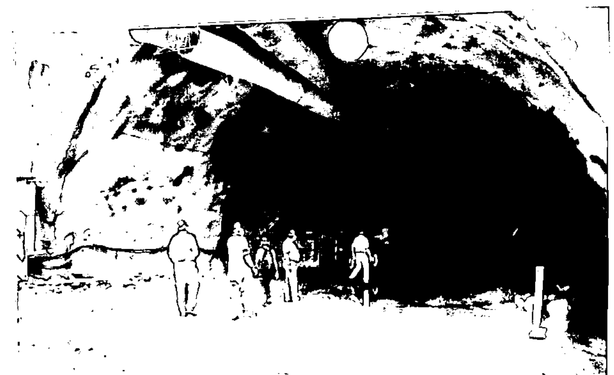
Segment	Start*	End**	Length*
Introduction	"This idyllic spot in the mountains ..."	"Dams, coming next on Building Big."	3:30
Dam Basics: tradeoffs; problem-solving; dam shape; waterproof clay core; dam failure	(3:30) Igaicu Falls	"... it took another 4,500 years for people to build another dam."	6:15
Aswan High Dam Politics: Nile flood cycle; financing the dam	(9:45) Sailboat	"... larger than the Great Pyramid and designed to last just as long."	5:45
Building the Aswan High Dam: diversion channels; coffer-dams; dam shape; grout curtains; tradeoffs	(15:30) Tractors in the desert	"... a single dam heralded a new age for a growing nation."	11:47
Hoover Dam Politics: problem-solving; financing the dam	(27:17) Hoover Dam	"... Hoover Dam as a new source of supply."	2:58
Hoover Dam Engineering: worker safety; gravity dams; arches; concrete; hydroelectric power	(30:15) Explosions	"... elsewhere and on rivers much bigger than the Colorado."	11:08
Environmental and Social Impacts: tradeoffs; models; spillways; resettlement	(41:23) Dams in Western U.S.	"... dams for the advancement of all civilizations."	11:37

Tunnels

Tuesday, October 31 at 8 PM

The need to cross a river, mountain, city, or ocean channel is sometimes great enough to justify the danger, difficulty, and expense of building a tunnel. The program describes the methods and machines involved in burrowing through the solid rock of a hillside or the soft mud beneath a river.

Segment	Start*	End**	Length*
Introduction	"On the night of June 25, 1872 ..."	"Tunnels, coming next on Building Big."	2:44
Big Dig: problem-solving; tradeoffs	(2:44) Traffic on bridge	"... just as they once did in the greatest city of the ancient world."	2:01
Roman Tunnels: aqueducts; gravity; problem-solving	(4:45) Model of Rome	"... one of Roman engineering's most fundamental designs."	5:12
Canal Tunnels: arches; side support; materials	(9:57) Paw Paw tunnel	"... lost patience with such a slow means of transportation."	4:35
Hoosac Tunnel: problem-solving; explosives; surveying; measuring; worker safety	(14:32) Exiting canal tunnel	"... building even longer tunnels in a fraction of the time."	7:56
Soft-Ground Tunnels: Brunel family; problem-solving; tunneling shield	(22:28) Railroad tracks	"... engineers would have to find a better way."	9:59
Car Tunnels: subways; ventilation; problem-solving; fire	(32:27) London street traffic	"... need the best possible escape routes."	7:53
The Chunnel: symbolism; safety; tunnel boring machines	(40:20) English Channel	"... last uncharted frontier: the underground."	12:40



* **Start times and lengths of video segments are written as minutes:seconds.**

** **Script as of press time. Final broadcast version may reflect some differences.**

Engineer's Notebook

Name____________________

Date____________________

Activity Title____________________

Use this space to record your data or for a drawing or photograph of your results.

My Prediction

Explanation

What Happened

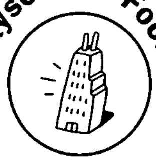
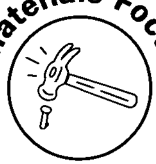
Explanation

·tivity Planning Grid

- **I only have one hour with the kids ... which activities should I do?**
- **What's a good combination of activities to do over three meetings?**
- **How can I integrate the BUILDING BIG video and Web resources with hands-on activities?**

You can use BUILDING BIG activities in many ways, from a one-time Activity Hour to a whole thematic unit. Below, we suggest some possible "paths" for different amounts of time. Choose a path that works for your schedule, or create your own plan using other activities in the guide.

The activity times listed in this guide are simply guidelines. An activity may take more or less time, depending on the particular kids. Trying the activity yourself first can help you predict how long it will take your group.

	If you have 1 hour ...			If you have 2 hours, add ...	
Path 1 Skyscraper Focus 	**1** Get kids exploring materials and thinking about creative solutions with **Newspaper Tower** (p. 28). **Building Small: Skyscrapers** (p. 38) shows one family meeting this challenge.	**2** Introduce **force, compression,** and **load** with the Hands-On Glossary mini-activities (p. 10) **OR** the **Loads Lab** on the Web.	**3** Finish by having kids apply what they've learned with **Skyscraper Building Challenge** (p. 34) **OR** the **Skyscraper Challenge** on the Web.	• Have kids explore a structural feature of skyscrapers with **Columns** (p. 18).	• Engage kids in the engineering design process with **Thinking Big** (p. 38).
Path 2 Bridge Focus 	**1** Get kids thinking about shapes in structures with **Straw Shapes** (p. 16) **OR** the **Shapes Lab** on the Web.	**2** Introduce **force, load, compression,** and **tension** with the Hands-On Glossary mini-activities (p. 10) **OR** the **Forces Lab** on the Web.	**3** Have kids apply what they've learned with **Paper Bridge** (p. 22).	• Have kids explore cables, a structural feature of many bridges, with **Hang in There** (p. 20).	• Give kids a hands-on feel for the forces at work in suspension bridges with **Suspension Bridge** (p. 24). Show "Brooklyn Bridge" or "Golden Gate" from **Bridges** (p. 3) to set the stage.
Path 3 Materials Focus 	**1** Introduce **force, compression, tension,** and **torsion** with the Hands-On Glossary mini-activities (p. 10) **OR** the **Forces Lab** on the Web.	**2** Get kids comparing different materials' strength with **Tug-Push-Twist-O'War** (p. 14) **OR** the **Materials Lab** on the Web.	**3** Have kids explore how to make a material stronger with **Paper Bridge** (p. 22).	• Engage kids in the engineering design process with **Thinking Big** (p. 38).	• Have kids apply what they've learned with **Bridge** or **Skyscraper Building Challenge** (p. 34).

If you have 3 meetings ...

Meeting 1

1. Get kids exploring materials and thinking about creative solutions with **Newspaper Tower** (p. 28).
2. Introduce **force** and **load** with the Hands-On Glossary mini-activities (p. 10).
3. Brainstorm possible structures for a **Local Wonders** project (p. 36). Choose a site. Make a plan for collecting information.

Meeting 2

1. Depending on what type of structure your Local Wonder is, choose a few mini-activities from the Hands-On Glossary (p. 10) to introduce relevant concepts.
   For bridges: **compression, tension, bending, cantilever, truss**
   For domes, skyscrapers, or other buildings: **compression, tension, shear, arch,** or **dome**
   For dams or tunnels: **compression, arch**
2. Visit the Local Wonder. Collect information about the structure (p. 36). Take photographs and/or draw the structure.

Meeting 3

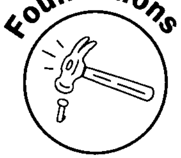
1. Depending on the Local Wonder, do an activity to introduce relevant concepts.
   For bridges: **Straw Shapes, Paper Bridge,** or **Hang in There**
   For buildings: **Columns** or **Straw Shapes**
   For dams: **Under Pressure**
   For tunnels: **Meeting in the Middle**
2. Analyze the information collected about the Local Wonder. Prepare submittal for the Web site (p. 36).
3. Visit the **Wonders of the World Databank** on the Web site **(pbs.org/buildingbig)** to compare your Local Wonder to other structures.

The Educator Ideas pages (pp. 14–34) suggest video segments that support each hands-on activity.

If you have 6 or more meetings ...

Meeting 1

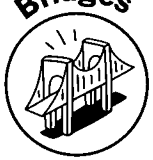
Foundations



1. **Newspaper Tower** (p. 28)
2. Hands-On Glossary (p. 10): **force** and **load**
3. **Straw Shapes** (p. 16)
4. Begin **Local Wonders** project (p. 36).

Meeting 2

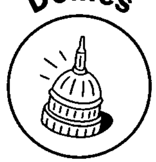
Bridges



1. **Paper Bridge** (p. 22)
2. Hands-On Glossary (p.10): **compression, tension, bending, truss**
   OR
   Forces Lab on the Web
3. **Suspension Bridge** (p. 24) or **Bridge Building Challenge** (p. 34)

Meeting 3

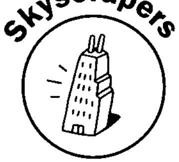
Domes



1. **Tug-Push-Twist-O'War** (p. 14)
   OR
   Materials Lab on the Web
2. Hands-On Glossary (p. 10): **dome**
3. **Geodesic Dome** (p. 26)

Meeting 4

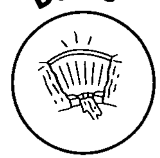
Skyscrapers



1. **Columns** (p. 18)
2. **Skyscraper Building Challenge** (p. 34)
3. Visit Local Wonder; collect information.

Meeting 5

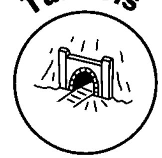
Dams



1. **Under Pressure** (p. 30)
2. **Dam Building Challenge** (p. 34)
3. Analyze Local Wonders information.

Meeting 6

Tunnels



1. **Meeting in the Middle** (p. 32)
2. **Tunnel Building Challenge** (p. 34)
3. Complete Local Wonders submittal (p. 36).

›oing Hands-On Science With Kids

Hands-on activities motivate kids to learn by actively involving them in the process of science. Kids become invested in activities when they generate the questions and help design the experiments to answer them. Here are some other reasons to do hands-on science:

Show kids that science is a process they use every day.
Engaging kids in the process of science teaches them that science is a way of thinking about the world, a particular way of asking questions and looking for answers. Kids learn that everyone can be a scientist. For example, point out everyday examples of asking questions, making observations, and drawing conclusions—such as deciding what to wear by looking out the window and checking the weather forecast.

Take advantage of kids' interests.
Involving kids' hands, senses, and even whole bodies in learning addresses their diverse learning styles: Some kids learn best when information is presented verbally, others visually, others physically, and so on.

You probably know that getting a group of 10- to 13-year-olds to sit still for half an hour can seem like a bigger challenge than building a bridge over the Grand Canyon. Instead, take advantage of kids' restlessness by giving their hands something to do. Kids this age are also developing their social skills. Working in small groups gives them permission to talk and interact, while helping them to develop teamwork skills they will need in the workplace and throughout their lives.

Survival Tips for Activity Leaders

Before the Activity

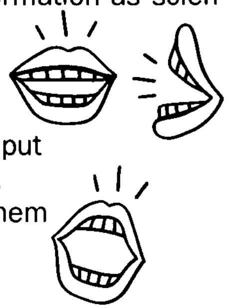
- Try every activity yourself before doing it with kids! Then you will know what to expect when the kids try it. You can modify materials or instructions based on your particular situation, or anticipate where your group will need help.
- Collect all materials, including supplies for any extensions. Have extras on hand so kids can "redo" activities.
- Divide materials into the correct amounts for each group. To streamline the activity time, place each group's materials together in a separate box.
- If your school or program cannot afford activity materials, seek a sponsor in your community. Kids can ask for donations or a discount from local businesses or community groups. (Be sure to check your organization's rules regarding advertising and sponsorship.)
- Build anticipation by displaying an unfamiliar term or interesting picture related to the topic for several days before doing the activity. Let kids wonder and speculate about the topic.
- Invite older kids, parents, or other adults to volunteer as activity leaders. Meet with any volunteers ahead of time.

Introducing the Activity

- Give clear instructions—fully explain what the activity is and what kids will be exploring. Give directions in multiple ways (e.g., verbally, written on the board).
- Form small groups of 2 to 4 kids (choose the groups for them). Most kids enjoy and do well working in groups.
- Remind kids to make a prediction about what they think will happen in the activity, and why.
- Depending on your group, avoid presenting activities as team-against-team competitions. Some kids may feel threatened or stressed out by competitions.

During the Activity

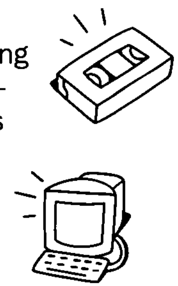
- Walk around and ask kids to describe what they're doing. Kids are sensitive about having the "right" answer, so emphasize the value of brainstorming and exploration, rather than right and wrong.
- Point out things that different teams are doing to the whole group. This lets kids know that the activity is doable and that they can make a contribution. Explain that this isn't "copying," but rather collaborating and building on new information as scientists do.
- If a group is not progressing, ask a leading question to put them back on track, rather than telling them what to do.



- Particularly in after-school programs, where kids may vary widely in age and ability levels, consider recording data as a group. Everyone gets to contribute, and it feels less like a school assignment.

After the Activity

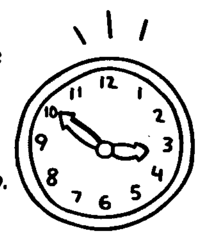
- Have kids assess what they've learned by explaining why they think their outcomes did or didn't match their predictions. **Ask: What do you know now that you didn't know before the activity?**
- Capture kids' reflections and explanations in writing or on audiotape or videotape. Use the responses to create a bulletin board, Web site, or newsletter to share with their families.



- Connect the big idea of the activity back to the "real world." For example, bring in pictures of structures that show how triangles are used in construction. If possible, take kids to see examples firsthand.
- Allow kids to take their products home to share with their families. Kids feel like the "expert" at home, and their families see what they are learning and doing. Most middle-school kids also like to reteach what they know to younger kids.

Classroom Management 101

- *Pass out materials only when you are ready for the kids to use them.*
- *Establish a signal—such as ringing a bell or quickly flashing the lights—that tells kids to stop working and listen. If kids are talking while you are, stop and wait. They will tend to quiet down in response to your silence.*
- *Engage an "itchy" kid by giving him or her a specific job to do.*
- *Provide extensions, such as the Build on It ideas in this guide, for those kids who race through an activity ahead of the rest of the group.*
- *Set ground rules; then consistently praise or criticize behaviors rather than individual kids.*
- *Share your enthusiasm for the subject—it will be contagious.*
- *Leave time to summarize, reflect on results, and clean up.*



- *Have a sense of humor, be patient, and maintain high expectations.*

22 23

Hands-On Glossary of BUILDING BIG Terms

These mini-activities help all kinds of learners get a feel for the physical science of structures. Each mini-activity requires no more than two materials and takes just five minutes. Use the mini-activities to introduce new terms or reinforce their meaning. These mini-activities will generate interest and curiosity that can spark a group discussion. To encourage further exploration, keep a running list of questions that arise.

Find the Web Connections on the BUILDING BIG site: pbs.org/buildingbig

FORCES

Force A push or pull on an object. For example, gravity is the force that pulls objects towards Earth's center. When an object is at rest, any force acting on it is balanced by an equal force in the opposite direction. If a new, unbalanced force acts on the object, the object will move in the same direction as the new force.

Imagine a house being pulled toward Earth's center by gravity, while the ground is pushing back up on the house. If the forces are equal (the house is on solid ground), the house doesn't move. If the forces are unbalanced (the ground is soft and muddy and pushes back with less force), then the house sinks down into the ground. If a new force, such as a bulldozer, acts on the house without a balancing force in the opposite direction, the house will move in the direction the bulldozer is pushing.

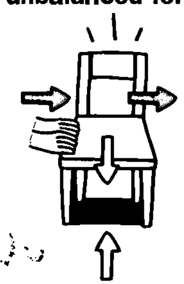
Mini-Activity

Force-ful Furniture

It's hard to visualize that many different forces may be acting on a building that seems to be standing still. Try this activity to help kids imagine these unseen forces.

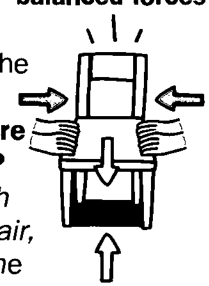
1. Place a **chair** in the middle of the floor. **Ask: Are any forces acting on this chair?** *(Kids will probably say no.)*
2. Invite a kid to gently push the chair a short distance across the floor. **Ask: What force just acted on this chair?** *(a push that made it move; an unbalanced force)*

unbalanced forces



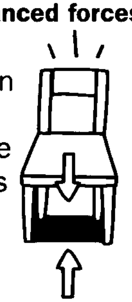
3. Repeat Step 2, this time with a second kid pushing back on the chair in the opposite direction so that it doesn't move. **Ask: Are any forces acting on the chair? Why doesn't it move?** *(Although two forces are acting on the chair, they are balanced. Therefore, the chair doesn't move.)*

balanced forces



4. Now repeat Step 1. Explain that even without someone pushing on it, forces are acting on the chair. The force of gravity is pulling down on the chair. But since the chair is not moving, there must be an equal force in the opposite direction—the floor is pushing back up.

balanced forces



Web Connection Forces Lab

Loads create a force on a structure.
Dead load The weight of the permanent, nonmoveable parts of a structure, such as the towers, cables, and roadway of a bridge.
Live load The weight of a structure's nonpermanent, moveable parts, contents, or "users," such as the traffic, people, and seagulls on a bridge. Environmental loads, such as wind, rain, and earthquakes, that can affect a structure temporarily are also live loads.

Mini-Activity

Name That Load

1. Have groups of kids look around the room and make a list of as many different loads affecting the room as they can.
2. List everyone's loads on the board. The group should decide whether each load is live or dead. *(Dead loads include the weight of the walls, ceiling, floor, and any permanent fixtures such as ceiling lights, wallpaper, paint, and windows. Live loads include things that are not fixed, such as furniture, people, signs and pictures hanging on the wall, plants, and wind blowing outside.)*
3. Have the group estimate the room's load, assuming the floor and walls weigh 50 lbs./sq.ft. and the ceiling weighs 30 lbs./sq.ft. Use a scale to weigh small furniture.

Web Connection Loads Lab

Compression A pressing force that squeezes a material together.

Mini-Activity

Feel the Pressure

Have pairs of kids place their palms together and gradually lean in toward each other. Ask them to describe how their arms feel. *(squeezed or pushed together)* Columns and bridge piers are examples of parts of structures that are in compression.

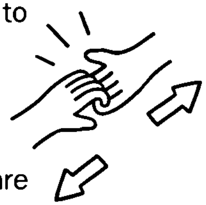
Web Connection Forces Lab

Tension A stretching force that pulls on a material.

Mini-Activity

Feel the Stretch

Have pairs of kids link fingers as shown and lean away from each other. Ask them to describe how their arms feel. *(stretched or pulled apart)* Elevator cables and the cables of suspension bridges are examples of parts of structures that are in tension.



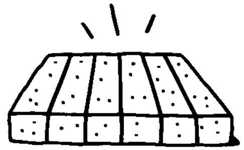
Web Connection Forces Lab

Bending A combination of forces that causes one part of a material to be in compression and another part to be in tension.

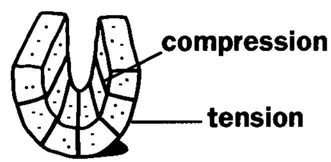
Mini-Activity

Sponge Beam

1. With a **permanent marker,** draw a series of lines crosswise on the top and bottom of a soft **kitchen sponge.**



2. Pass the sponge around. Have kids bend the sponge into a U-shape, and observe what happens to each set of lines. *(The lines on the top get closer together and the lines on the bottom spread farther apart.)* **Ask: Where is this sponge in compression?** *(the top side)* **In tension?** *(the bottom side. Bending is common in structures; for example, a horizontal beam that supports a floor or a bridge deck experiences bending. Reinforced concrete resists bending because of its combination of concrete, which resists compression well, and steel bars, which resist tension well.)*



Web Connection Forces Lab

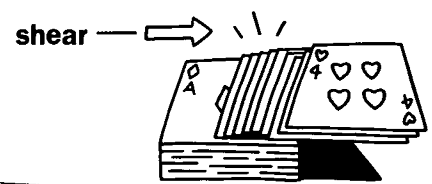
Shear A force that causes one part of a material to slide past another.

Mini-Activity

Shear the Deck

Place a **deck of cards** on a table. Invite a kid to push sideways on the top part of the deck so the cards "smear" sideways, demonstrating the sliding action of shear force. Shearing stress on two parts of a structure that are bolted or nailed together can break the bolts or nails in two.

Web Connection Forces Lab



Torsion A twisting that can result from an unevenly placed load.

Mini-Activity

Feel the Twist

Have pairs of kids hold each other's right wrists and gently rotate their arms. Ask them to describe how their arms feel. *(twisted)* Wind pushing unevenly on a structure can cause torsion.

Web Connection Forces Lab

Hands-On Glossary, continued

STRUCTURES

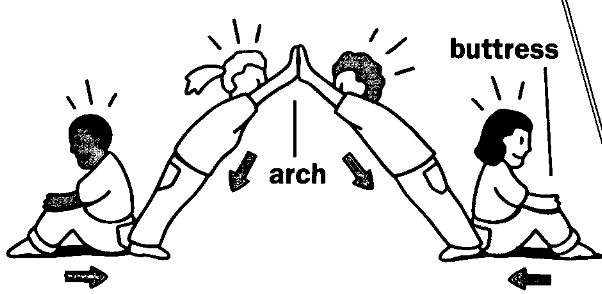
Arch A curved structure that converts the downward compression force of its own weight, and of any weight pressing down on top of it, into a force along its curve. This results in an outward and downward force along the sides and base of the arch.

Buttress A side support that counteracts an outward pushing force, the way bookends keep books on a shelf from sliding sideways. Buttresses are often used to support the sides of arches and tall cathedral walls, where they counteract the outward thrust.

Mini-Activity

Human Arch

1. Have two kids form an arch by placing their palms together and leaning toward each other, sliding their feet as far back as they can. Caution them not to lose their balance. **Ask: Where do you feel a push or a pull?** *(pushing on their hands)*
2. Have a third kid gently pull down on the top of the arch to test its strength. **Ask: How difficult is it to break the arch?** *(not difficult)*
3. Have the group brainstorm ways for two more kids to join the arch and make it stronger, but without breaking up the space beneath the arch. Guide them to the idea of adding buttresses by asking the arch-makers how stable their legs feel. Then repeat Step 2 and compare the results. *(The buttresses exert an inward force on the sides of the arch that balances the outward force created by the load pressing down on the top of the arch.)*



Video Connection "Roman Bridges" from **Bridges** (p. 3)

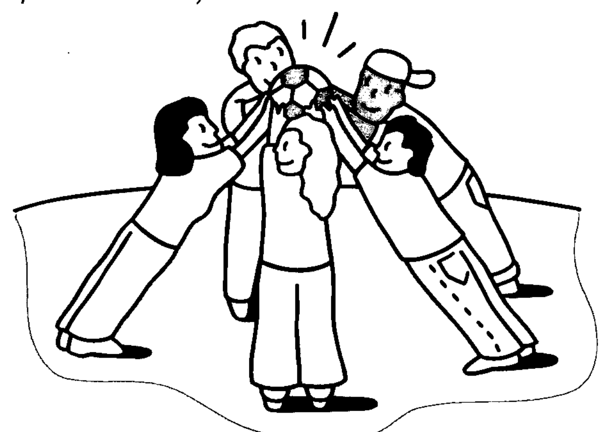
Web Connection Shapes Lab

Dome A curved roof enclosing a circular space; a three-dimensional arch.

Mini-Activity

Human Dome

1. Have five kids stand in a circle around a **soccer ball.** The kids should all place their fingertips on the ball and lift it, leaning in toward the center of the circle and sliding their feet back.
2. Reach into the center and push down gently on the ball. **Ask: Where could the dome use more support?** *(Adding five seated kids as buttresses at the base of each "rib" of the dome will help the dome support more compression. As in an arch, the buttresses exert an inward force on the sides of the dome that balances the outward force created by the load pressing down on the top of the arch.)*



Video Connection "Pantheon" from **Domes** (p. 4)

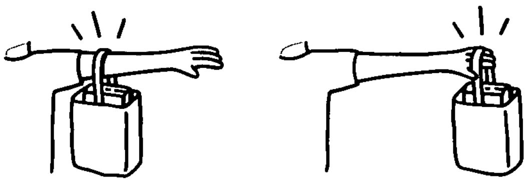
Web Connection Dome Overview

Cantilever A projecting structure supported at only one end, such as a shelf bracket or diving board.

Mini-Activity

Arm Cantilever

1. Place a **heavy book** in a **bag with straps. Ask: Do you think you could support this weight with one arm?** *(Kids will probably say yes.)*
2. Have kids first place the bag straps over their arms near the shoulder, and then over the tips of their fingers. **Ask: Is it equally easy to support the weight in both places?**



(It is much easier to support the bag close to the shoulder, near the fixed base of the cantilever, then at the unsupported fingertip end. Cantilevers support loads by bending. A cantilever can support more weight closer to its fixed end. Examples of cantilevers in structures include balconies and awnings.)

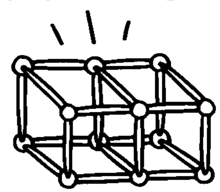
Web Connection Bridge Overview

Truss A skeleton-like structure composed of struts (short straight pieces), some in compression and some in tension, joined to form a series of triangles.

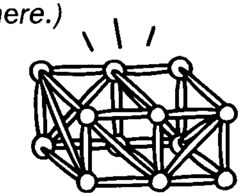
Mini-Activity

Toothpick Truss

1. Have kids construct a rectangular box as shown here by joining **toothpicks** with **small white beans or navy beans**, soaked overnight before the activity, or **gumdrops.** Have them test its stability by pressing down on it and wiggling it.



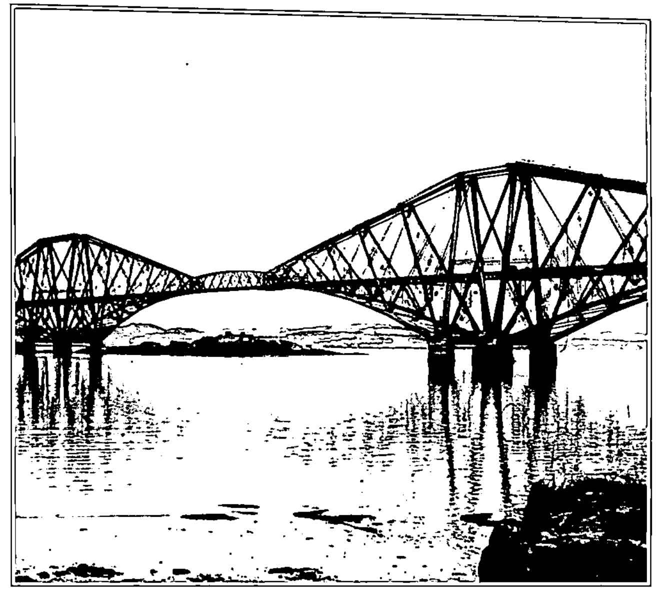
2. Now challenge kids to add more materials to strengthen the box. *(Kids will probably find that they can stabilize the box by adding cross-pieces and triangular braces, as in the example shown here.)*



3. Have kids extend their trusses and see how wide a gap they can cross.

Video Connection "Trusses" from **Bridges** (p. 3)

Web Connection Loads Lab



Scotland's dramatic Firth of Forth Bridge gets its strength from cantilevers and trusses. The video segment "Trusses" from Bridges (p. 3) explains how it works.

30

31

Time
20–30 minutes

Materials
(per group of three)
Samples of 6 or 8 different materials, such as string or yarn; popsicle sticks; pipe cleaners; clay; strips of kitchen sponge; rubber erasers; rubber bands; paper-towel tubes; pencils; strips of cardboard or aluminum foil; drinking straws; ceramic tiles; strips of cloth

Video Connection
After the activity, use "Iron Bridges" from **Bridges** (p. 3), "U.S. Capitol" from **Domes** (p. 3), or "Eiffel Tower" from **Skyscrapers** (p. 4) to show how the choice of materials affects structures.

Web Connection
pbs.org/buildingbig
Materials Lab

Additional resources are listed on page 38.

Icebreaker

Use a **rope** to demonstrate the three tests. Have two kids tug on the ends of a rope (tension), then push the ends together (compression), and finally twist the ends of the rope (torsion). With each test, have the group suggest a rating using the scale on the Activity Handout on page 15. *(The rope is strong in tension but weak in compression and torsion.)*

Lead the Activity

- Discuss how kids can fairly compare the different materials. Encourage them to find a consistent way of handling the materials. For example, besides pushing a material together between their hands, another way to test for compression is to place the sample on a tabletop and press down on it.
- Discuss how some materials are flexible under a type of stress—they change shape as opposed to breaking outright. When might flexibility be desirable? When is stiffness required? *(Parts of structures such as the cables of suspension bridges that are built to withstand shaking caused by wind gusts often have some "give." Other parts of structures, such as floor beams that support great weights, need to be rigid.)*

The Big Idea

Different materials have varying abilities to withstand compression, tension, and torsion. Materials scientists study these properties of construction materials using machines that apply enormous loads to the samples and measure their ability to withstand the stresses that result. Results may differ somewhat due to the limitations of these testing methods, but in general kids will find results similar to these.

Strong in tension: string, yarn, pipe cleaner, popsicle stick, ceramic tile, cardboard, drinking straw, cloth, rubber band (strong but very flexible), rubber eraser, paper-towel tubes, pencil

Strong in compression: popsicle stick, clay (limited), ceramic tile, rubber eraser, paper-towel tubes (limited), pencil

Strong in torsion: ceramic tile, rubber eraser (limited), paper-towel tubes, pencil

Build on It

Possible outcome: Kids can compare shapes and sizes of the same material, such as a flat piece of cardboard and a cardboard paper-towel tube. They will find that the curved shape of the cardboard tube increases its stiffness and resistance to compression and torsion. Follow up with the **Shapes Lab** on the Web site.

Make Connections

Language Arts Have kids choose a material and write a paragraph from that material's point of view, explaining what it feels like to be in compression, tension, or torsion. Encourage kids to be creative and to use descriptive verbs and adjectives. Kids can team up to read aloud and act out each other's paragraphs.

Tug-Push-Twist-O'War

Activity Handout

How tough is this stuff?

Have you ever seen a paper skyscraper? Probably not, because paper is not strong enough to withstand the forces acting on a skyscraper. Hold a "tug-push-twist-o'war" to find out which materials can best withstand different forces.

What You Need

Three samples each of 6 or 8 materials, such as yarn, popsicle sticks, pipe cleaners, clay, sponges, erasers, rubber bands, paper-towel tubes, pencils, cardboard, aluminum foil, drinking straws, tiles, or cloth

Make a Prediction

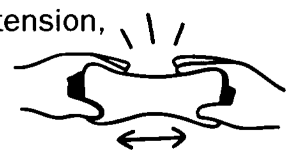
Before you test the materials, predict which ones will be strongest in tension, which in compression, and which in torsion.

Try It Out

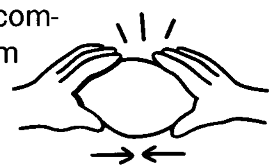
1. First make a table to record your results. You'll rate each material for each type of stress.

Material	Tension Rating	Compression Rating	Torsion Rating
Paper	2 (when we pulled slowly)	1	1

2. **Tug:** To test the material in tension, pull on it from both ends. Record your rating and any observations in the table.



3. **Push:** To test the material in compression, push it together from both ends. Record your rating and any observations.



4. **Twist:** To test the material in torsion, twist the two ends in different directions. Record your rating and any observations.

5. Repeat steps 2–4 for each material.

Rating Scale

1 **Very weak! It crumples or breaks with hardly any force.**
2 **Only fair—it can't withstand much force.**
3 **Pretty good—it takes a lot of force to break it.**
4 **Super strong! We can't break it.**

Explain It

- Which materials were strongest in resisting each type of force? Did any of these results surprise you? Why or why not?
- Which materials were strongest across all three tests? How would you describe those materials?

Build on It

Does shape affect how well a material performs in the Tug-Push-Twist-O'War? Choose a material and design a test to answer this question.

Straw Shapes

Educator Ideas

Time
10–15 minutes

Materials
(per group of two)
- 7 straws
- 14 paper clips

Alternate Materials
Toothpicks and dried peas or white beans, soaked overnight before the activity

Video Connection
After the activity, show "Geodesic Domes" from **Domes** or "Trusses" from **Bridges** (p. 3) to show the importance of triangles in structures.

Web Connection
pbs.org/buildingbig
Shapes Lab

Additional resources are listed on page 38.

Icebreaker

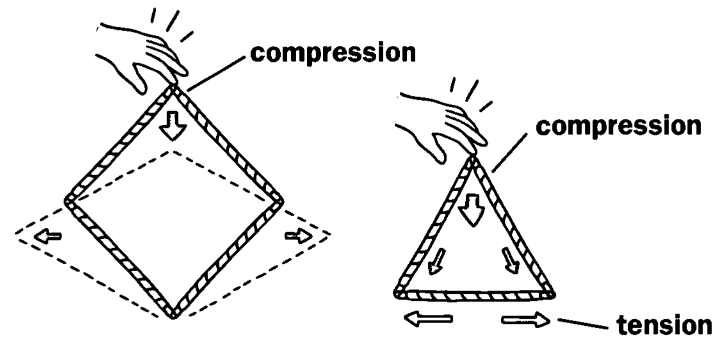
Give kids the straws and paper clips. Have them brainstorm adjectives that describe the straws. **Ask: How do the straws bend? How useful do you think straws are as a building material?** *(not very useful)* **How might the straws' qualities change depending on how they are used?** *(Kids may suggest reinforcing the straws or changing their shape.)*

Lead the Activity

- Demonstrate how to connect straws with paper clips, as shown on page 17. Push a paper clip inside one end of a straw. Link another clip to the first clip and push the second clip into the end of a second straw.
- As groups finish building their shapes, talk about their plans for testing them. Will one person do the testing or will they take turns? How can they make the test as "fair" as possible? *(The same person, or both people, should test both structures.)*

The Big Idea

Straws arranged into triangles form more stable shapes than straws arranged into squares. When compression force is applied to the joints, a triangle changes shape less than a square. When compression is applied to a square, as shown below, the joints rotate easily, and the shape changes. In a triangle, the compression in the two sides is balanced by the tension in the cross-piece at the bottom, which pulls the sides back together. This balancing of forces results in a more stable structural form.



To reinforce the importance of triangles, take kids on a "shape" scavenger hunt, through photographs or during their daily travels, looking for examples of shapes used in structures. Scaffolding cross-braces and trusses under bridges and railroad overpasses are good places to see triangles.

Build on It

- Ask kids how they could add two straws to make a four-sided straw square stronger. **Possible outcome:** Use a diagonal cross-piece made from two straws as a triangular brace. The triangle shape stabilizes the joints of the square and keeps them from changing shape when a force is applied. This is the prinicple behind trusses.
- Encourage kids to incorporate triangles into a three-dimensional structure. **Possible outcome:** Kids may find that a tetrahedron (three triangular sides with a triangular base) is very strong.

Make Connections

Math Discuss the different two-dimensional straw shapes as polygons. As a group, make a table listing names of polygons and how many sides each has, and have kids build each polygon out of straws. As the number of sides increases, do the polygons become more or less stable?

Straw Shapes

Activity Handout

Which shape is more stable, a triangle or a square?

You'll test the stability of a triangle and a square by standing them on a table and pressing on them. The one that changes shape less is more stable.

What You Need

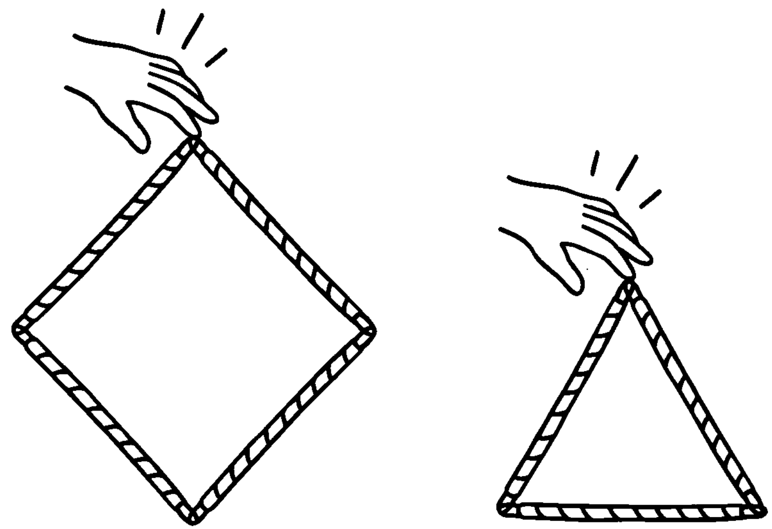
- 7 drinking straws
- 14 paper clips

Make a Prediction

Predict which shape will be more stable. Why do you think so?

Try It Out

1. With your partner, build a triangle and a square from the straws and paper clips. To connect two straws, slip the wide end of a paper clip into the end of one straw. Hook a second paper clip to the first. Now insert the wide end of the second clip into a second straw.



2. Compare the stability of the shapes. Stand each shape up and press down on the top corner. What happens? How much does each one bend and twist? How hard can you press down on each shape before it collapses?

Explain It

Compare the results of your tests on the triangle and square. Which shape was more stable? What do you think made it more stable? How might this shape be used in large structures?

Build on It

- Can you reinforce the less stable shape by adding no more than 2 straws and 4 paper clips?
- Now that you know more about shapes, build the most stable structure you can using no more than 20 straws and 40 paper clips. How much weight can your structure support?

Time
10 minutes

Materials
(per group of two)
- 2 empty toilet-paper tubes (but have lots of extras, as kids will want to try again and again)
- sand or salt
- dishpan, tray, or cardboard box lid to catch any spilled sand or salt
- masking tape
- sturdy chair
- funnel

Video Connection
After the activity, show "Chicago" from **Skyscrapers** (p. 4) to demonstrate how columns support loads in compression.

Web Connection
pbs.org/buildingbig
Forces Lab

Additional resources are listed on page 38.

Icebreaker

Hold up a toilet-paper tube and announce that you are going to stand on it. **Ask: Do you think this tube will hold me up?** *(Kids will probably say no; if they say yes, ask what the maximum weight they think it can support is—a car? an elephant?).* Now introduce the activity challenge—to find a way to make a toilet-paper tube support a person's weight.

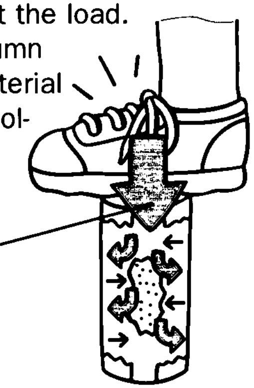
Lead the Activity

- Supervise this activity carefully to ensure kids' safety. Limit testing to one person at a time. Have someone sit in the chair to hold it steady while the tester leans on the back of the chair.
- Instruct kids to step evenly on the top of the tube. They may observe on their own that a slight lean in any direction causes the tube to crumple more quickly on that side. Placing a piece of cardboard over the top of the tube may help distribute weight more evenly.

The Big Idea

Kids may find different solutions to increase the strength of the tube. Reinforcing the sides of the tube by wrapping it with bands of tape makes it a little stronger. The tape increases the stiffness of the sides of the tube and helps it resist buckling under the load.

Placing tape over the ends of the tube and filling the tube with sand or salt increases its strength enough to hold a person's weight. The load is distributed evenly by the material inside the tube. The sand's tendency to spread out is resisted by the sides of the tube, which hold it in and enable it to support the load. In construction, a thin-walled column can be filled with inexpensive material which still greatly increases the column's strength in compression.



Build on It

Supply additional materials (such as marbles or pebbles) for kids to test their predictions. **Possible outcome:** Kids may find that the smaller particles work better because they push out more evenly against the sides of the column.

Make Connections

Math Use the tubes to discuss circumference, diameter, and area of circles. Ask kids to predict which can support a greater weight: a single column with a circumference of 24 cm or three columns with circumferences of 8 cm each? Have them test their predictions.

Possible outcome: Kids will probably find that the answer depends on how they arrange the columns. Three smaller columns arranged a small distance apart in a triangular shape may support more weight than a single large central column.

Can a toilet-paper tube support your weight?

Columns are often used to hold up heavy loads, such as the roofs of buildings. The heavy load pushes on the column, putting it in **compression.** So, a good column should be very strong in compression.

What You Need

- 2 empty toilet-paper tubes
- sand or salt
- dishpan, tray, or cardboard box lid
- masking tape
- sturdy chair
- funnel

Build on It

Is there any difference in strength between a column filled with small particles, like sand or salt, and a column filled with big particles, like marbles or pebbles? Make a prediction and test it.

Make a Prediction

Predict whether a toilet-paper tube can withstand the compression caused by your weight. Explain the reason for your prediction.

Try It Out

1. Place an empty dishpan, tray, or box lid on the floor. Stand an empty toilet-paper tube (the column) on one end in the pan.

2. While holding on to the back of the chair with both hands, gradually press straight down on the top of the column with one foot. Continue increasing your weight on the column until it collapses. Use this scale to rate the column's strength:

   1 **Very weak! It crumples or breaks with hardly any force.**
   2 **Only fair—it can't withstand much force.**
   3 **Pretty good—it takes a lot of force to break it.**
   4 **Super strong! We can't break it.**

3. Observe the collapsed tube to see where it failed. How can you make the column stronger, using only tape and sand? Repeat Step 2 using the second toilet-paper tube and your new design.

Explain It

How did the strength ratings for the two columns compare? Explain what you think accounted for any difference. Were you surprised by the results of this activity? Why or why not?

Hang in There
Educator Ideas

Time
25–30 minutes

Materials
(per group of four)
- 60 cm (about 2 ft.) each of several cables, such as yarn, thread, dental floss, and fishing line
- 2 empty 2-liter plastic bottles with caps, or a metal bucket with handle
- 2 pipe cleaners, or a metal "s"-hook
- broomstick or pole
- dishpan
- measuring cup
- funnel
- sand, salt, or water

Advance Preparation
For younger kids or kids with fine-motor difficulties, you may want to tie loops in the cables ahead of time to reduce the time needed for this activity.

Video Connection
After the activity, use "Golden Gate" from **Bridges** (p. 3) to show some ways to make cables stronger.

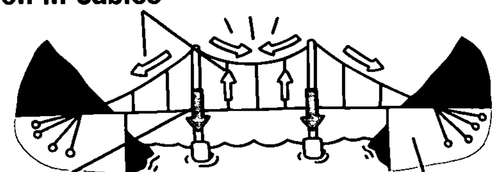
Web Connection
pbs.org/buildingbig
Forces Lab

Additional resources are listed on page 38.

Icebreaker
Introduce the term "cable" by discussing elevators. Hold up a piece of **yarn**, **string**, or **fishing line**. **Ask: Would you ride in an elevator hung from cables made of this material?** *(Kids will probably say no.)* To show that it is surprisingly difficult to break the material in tension, wrap the ends of the cable around two **pencils** and pull the pencils apart. (The pencils keep you from hurting your hands.) Now introduce the activity—measuring just how much weight different cables can support.

Lead the Activity
- Instruct kids to pour the sand only as fast as it passes through the funnel. This prevents clogging the opening and allows more accurate measurement of how much sand the cable can hold before it breaks. If you are using water, tell kids to support the bottle as they add each cupful of water, and then replace the bottle cap before letting go of the bottle again. This will prevent spills when the cable breaks.
- As the load gets heavier, have kids move the desks or chairs closer together to ensure that the broom handle doesn't break. If the soda bottle touches the floor before a cable breaks, the pole can be raised and held by hand.

The Big Idea
Unlike many other parts of structures, which experience combinations of compression and tension, cables support loads purely in tension. Thicker cables are not necessarily stronger than thinner cables. The particular material of the cable, as well as how the cable is formed, determine its strength and stretchiness. In this activity, kids will likely find that sewing thread is relatively weak and that fishing line is strong, with yarn and dental floss falling in between. Kids will probably be surprised at how much weight the different cables can support.



Different uses require cables with different degrees of stretchiness. For example, the non-stretchy wires that support tall radio towers keep the towers from moving too much. On the other hand, because ship mooring cables are stretchy, they can act as shock absorbers during storms. A fishing line's stretchiness allows it to absorb a sharp but short jerk that would snap a non-stretchy cable.

Build on It
Possible outcome: Kids may try twisting or braiding several lengths of cable or wrapping different kinds of cable together. Draw comparisons to the actual methods used in suspension bridges and elevator cables. (You may wish to show the video segment suggested at left.)

Make Connections
Music In many musical instruments, putting metal or gut strings into different levels of tension creates a range of sounds. Kids can experiment with rubber bands stretched across pushpins on a board to find the right lengths to produce an eight-note scale.

Hang in There

Activity Handout

What's the strongest cable?

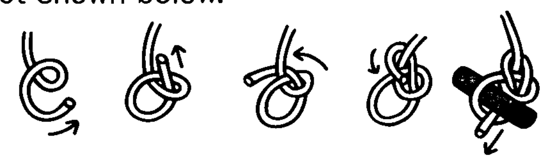
Cables are used to support hanging loads such as roadways and elevators. A hanging load pulls on the cable, putting it in **tension.** So, a good cable should be very strong in tension.

Make a Prediction

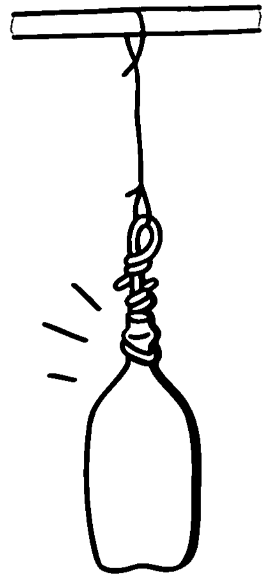
Predict which cable you think is strongest. Explain why you think so. How many cupfuls of sand in a soda bottle do you think this cable can support before it breaks?

Try It Out

1. Tie one end of each cable to a broomstick using the knot shown below.



2. Tie a loop at the other end of each cable. Hold the loop open with one finger while you tighten its knot.
3. Now make a load tester. Wind a pipe cleaner tightly around the neck of a plastic bottle. Form the other end of the pipe cleaner into a hook.
4. Place the broomstick between two desks or chairs so the cables hang down. Hang the load tester from the bottom loop of the first cable, and wind the pipe cleaner tightly around itself. Place a pan underneath the bottle.
5. Place a funnel in the bottle. Slowly add the load (sand, salt, or water), one cupful at a time. Record how many cups you can add before the cable breaks. (You may need to add another hanging bottle.)
6. Empty the bottle and repeat steps 4–5 with the next cable.



What You Need

- 60 centimeters (about 2 ft.) each of several cables, such as yarn, thread, dental floss, and fishing line
- 2 empty 2-liter plastic bottles
- 2 pipe cleaners
- broomstick or pole
- dishpan
- measuring cup
- funnel
- sand, salt, or water

Explain It

- Which cable held the most weight? Compare the strongest and weakest cables. How are they different? Compare the two strongest cables. How are they alike?
- Which cables stretched before breaking and which did not? Can you think of any situations where a stretchy cable would be helpful or where it would be a problem?

Build on It

Can you design a way to make your strongest cable stronger? You can use any of the materials from this activity. How much weight can your improved cable hold before it breaks? How did your design make the cable stronger?

Paper Bridge

ucator Ideas

Time
20–30 minutes

Materials
(per group of two)
- plain paper (such as photocopier paper)
- 5 paper clips
- ruler
- 2 books or blocks
- at least 100 pennies, metal washers, or other small weights
- scissors

Video Connection
After the activity, show "Environmental Loads" from **Bridges** (p. 3) to spark kids' ideas for modifying their bridges.

Web Connection
pbs.org/buildingbig
Shapes Lab

Additional resources are listed on page 38.

Icebreaker

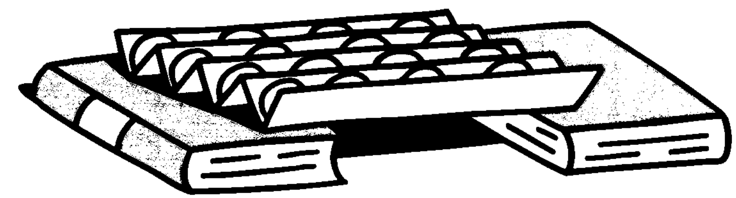
Hold up a single piece of paper. **Ask: How many pennies do you think a bridge made out of this paper can hold?** After kids make some guesses, lay the sheet of paper flat across two books placed 20 cm (about 8 in.) apart. With the kids keeping count, place pennies on the bridge, near the middle, until the bridge fails. *(It will hold only a few.)* Now introduce the activity challenge.

Lead the Activity

- Ask kids questions about their designs. What can they do to the paper to make it stronger? Should they cut the paper? How can they use the paper clips? *(Kids may accordion-pleat the paper, roll it, or cut it into strips and weave them together. The paper clips could be used to stiffen folded paper.)*
- Have a discussion about different types of bridges kids have seen. How long were they? How tall? What were the bridges designed to transport (e.g., trains, cars, people)? What other considerations went into designing the bridges (e.g., earthquakes, boat traffic)?
- As kids test their bridges, suggest that they observe the bridges closely to determine where they fail.

The Big Idea

Changing the shape of a material can change the way it resists forces. Although a piece of paper seems flexible and weak, it can be folded, rolled, twisted, or otherwise altered to support quite a bit of weight. Folding the paper helps it to resist bending forces created by the live load of the pennies on top of the bridge. The paper can be folded into the shape of an I-beam or accordian-pleated, as shown below. Rolling the paper around the pennies and fastening the ends with paper clips is another possible solution.



Build on It

- Use this opportunity to discuss that while engineers cannot build multiple full-size bridges to test their ideas, they use models and computer simulations to test and redesign structures.
- **Possible outcome:** Kids will probably find that the bridge can support more weight distributed along the bridge than at a single point.

Make Connections

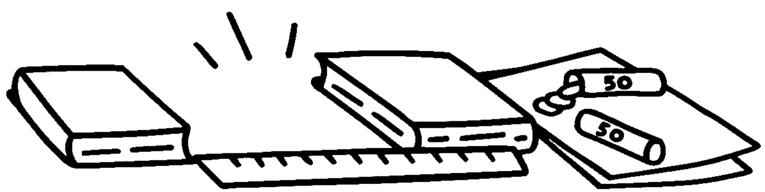
Social Studies Have small groups of kids each choose a bridge featured in the video or another large bridge. Each group should create an advertisement for their bridge that highlights what they think is most important to the people in the bridge's community. Encourage kids to use both text and images to convey their message.

Paper Bridge

Activity Handout

Can you build a bridge that holds 100 pennies, using 1 sheet of paper and up to 5 paper clips?

A bridge must support its own weight (the **dead load**) as well as the weight of anything placed on it, like the pennies (the **live load**). Your paper bridge must span 20 centimeters (about 8 in.). The sides of your bridge will rest on two books and cannot be taped or attached to the books or the table.



What You Need

- plain paper
- 5 paper clips
- ruler
- 2 books or blocks
- at least 100 pennies or other small weights
- scissors

Make a Prediction

Describe how you think the bridge should be constructed in order to support its dead load plus the live load of the pennies.

Try It Out

1. Discuss possible ideas with your partner before you start building. What can you do to the paper to make it stronger? When you have decided on a design, construct your bridge.
2. Place the bridge across two supports that are 20 cm apart. Remember that the space below the bridge must be clear to allow boats to pass!
3. To test your bridge, load it with pennies one at a time, until it collapses. Record how many pennies your bridge supported.

Explain It

Describe how well your bridge supported its dead load and the live load you placed on it. Was the bridge as strong as you thought it would be? Where did it fail?

Build on It

- Redesign your bridge and test it again, using a new sheet of paper. How does your second attempt compare? How can engineers test their plans for building a full-size bridge?
- Is there a difference in the load your bridge can hold if you put the load in the center of the bridge compared to spreading it out along the bridge? Make a prediction and test it.

Suspension Bridge

Educator Ideas

Time
30–40 minutes

Materials
(per group of two)
- 7 drinking straws
- masking tape
- 100 cm (about 4 ft.) dental floss or thread
- scissors
- 4 large paper clips
- paper cup
- pennies, metal washers, or other small weights
- ruler

Video Connection
Before the activity, show "Brooklyn Bridge" from **Bridges** (p. 3) to explain the forces supporting a suspension bridge.

Web Connection
pbs.org/buidingbig
Bridge Overview

Additional resources are listed on page 38.

Icebreaker

Tie a piece of **string** to a **shoe** or other weight. **Ask: Who can lift this shoe in the air only by pulling down on the string?** *(Guide kids to the solution of passing the string over the back of a chair or other support and using it as a pulley to lift the shoe.)* Discuss how this design converts the pulling-down force into a force that pulls up on the weight.

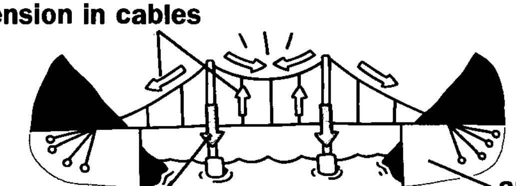
Lead the Activity

- This basic suspension bridge design can be applied using other materials to build larger, stronger bridges. For example, kids can use paper-towel tubes and string to build the bridge deck and cables, and use the backs of two chairs as the towers.
- To help kids understand how forces act in a suspension bridge, have them experiment with attaching the cables from the bridge deck only to the tops of the towers, instead of extending them back down to the surface at the ends of the bridge. **Ask: How strong is the bridge this way? Why?** *(This model is less strong than the model in which the cables extend back down to the ground on the other sides of the towers. A load on this bridge deck pulls the tips of the towers inward. There is no balancing tension pulling the towers back out toward the ground.)*

The Big Idea

Kids should find that adding the cables to their straw bridge and anchoring the cables on both sides significantly increases the load that the bridge can support.

A suspension bridge's cables and towers transmit the dead load of the bridge deck and the live load of traffic to the massive anchor blocks at each end of the bridge. The tension in the cables leading up from the bridge deck is balanced by the tension in the cables leading to the anchor blocks, as well as the compression in the towers. The anchor blocks must be massive enough to resist the tension in the cables caused by the weight of the bridge deck.



Build on It

Possible outcome: Kids can make their bridge decks longer by creasing the end of one straw and inserting it into the end of another straw. Kids can try to build as long a bridge as possible that can support a given amount of weight.

Make Connections

Social Studies After showing "Brooklyn Bridge" from **Bridges** (p. 3), have kids each choose a member of the Roebling family and write or record an entry from that person's diary describing his or her role on and feelings about the bridge.

Suspension Bridge

Activity Handout

What's the secret of suspension?

A suspension bridge's cables are beautiful to look at, but they also enable the bridge to cross large spans. Make a model suspension bridge to see how it works.

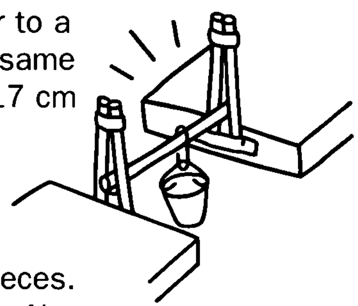
Make a Prediction

After you test the strength of the beam bridge in Step 4, predict how many pennies your suspension bridge will support.

Try It Out

1. Cut two short pieces of straw, each 3 centimeters (about 1.25 in.) long. For each tower, tape two straws on either side of a short piece of straw, as shown. Tape the long straws together at the top, too.

2. Tape one tower to the edge of a desk or chair. Tape the second tower to a second desk or chair of the same height. Position the towers 17 cm (about 7 in.) apart.



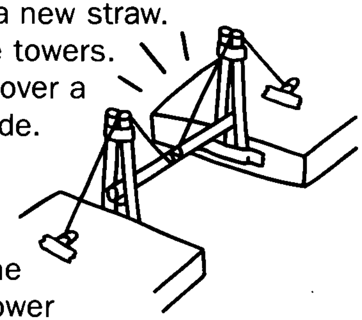
3. Place another straw between the towers so its ends rest on the short pieces. This straw is the bridge deck. Now you have a simple beam bridge.

4. Make a load tester by unbending a large paper clip into a V-shape. Poke the ends of the paper clip into opposite sides of a paper cup, near the rim. Use a second paper clip to hang the load tester over the bridge deck. Record how many pennies the paper cup can hold before the bridge fails.

What You Need

- 7 drinking straws
- masking tape
- dental floss or thread
- scissors
- 4 large paper clips
- paper cup
- pennies or metal washers
- ruler

5. Now change the beam bridge into a suspension bridge. Tie the center of a 100-cm (about 4 ft.) cable around the middle of a new straw. Place the straw between the towers. Pass each end of the cable over a tower and down the other side.



6. To anchor the bridge, wrap each end of the cable around a paper clip. Slide the paper clips away from the tower until the cable pulls tight. Then tape the paper clips firmly to the desks. Test it again.

Explain It

Can you identify the forces acting on the loaded suspension bridge? Which parts of the bridge are in compression? Which parts are in tension?

Build on It

- Can you design and build a straw suspension bridge that spans a gap twice as wide and supports the same amount of weight? What parts of the bridge design need to change? Try it.

Geodesic Dome

Educator Ideas

Time
60–90 minutes (depending on number of participants)

Materials
(for the whole group)
- many newspapers
- measuring tape
- masking tape (colored, if possible)
- markers, glitter, beads, and glue for decorating, if desired
- hand wipes for cleanup

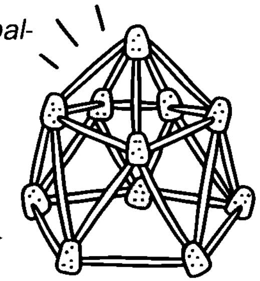
Video Connection
Before the activity, show "Geodesic Domes" from **Domes** (p. 3) to introduce domes constructed from triangles.

Web Connection
pbs.org/buildingbig
Dome Overview

Additional resources are listed on page 38.

Icebreaker

- Have kids form domes by bending a few sheets of **newspaper** into a bowl shape. They will quickly note that the domes cannot support much of a live load. Then show kids the video segment suggested at left or pictures of geodesic domes (such as Epcot Center in Orlando). **Ask: What shapes do you notice in these domes? Why do you think these shapes were used?** *(Triangles; they are a stable shape because compression acting at one joint is balanced by tension along the opposite side.)*
- Have kids build miniature geodesic domes using **gumdrops** and **toothpicks**. Let them experiment on their own or direct them to build the model shown here.

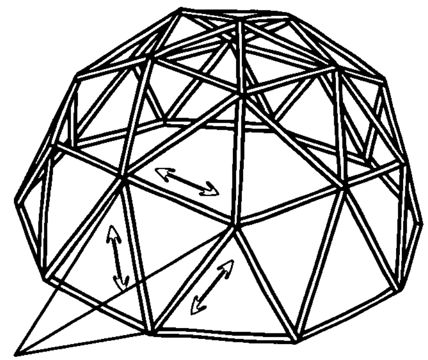


Lead the Activity

- Rolling the newspapers and measuring the tubes is time-consuming. This activity works best with large groups, so that each kid is only rolling a few tubes. Assign at least one adult "foreperson" to coordinate the dome assembly. Have kids decorate their tubes and attach them to the growing dome with an adult's help.
- The dome's joints are weak spots. Use plenty of tape to reinforce them.
- For safety, remind kids not to climb on the completed dome. Test the dome's strength by loading the top with magazines.

The Big Idea

A dome must support its own dead load as well as the live load of wind, rain, snow, or ice. The geodesic dome's strength is due to the fact that triangles are very stable shapes. It is difficult to distort a triangle; compression at one joint is balanced by tension along the opposite side (see **Straw Shapes** activity, p. 16). The geodesic dome's design distributes loads over all of the different triangles that comprise it.



Compression at the joints is balanced by tension in the sides.

Build on It

Possible outcome: Kids may add tension rings around the bottom of the dome or divide some or all of the triangular panels into smaller triangles.

Make Connections

Math Triangles are a shape that can be tesselated, or arranged to form a tiling pattern. Have kids predict what other shapes can be tesselated. *(hexagons, squares)* Kids can cut the shapes out of paper and test their predictions.

Geodesic Dome

Activity Handout

What's the strongest dome you can build out of newspaper?

A **geodesic dome** is a dome formed by joining triangles together. You can build a giant geodesic dome out of newspaper. First, gather some friends or family members to help you.

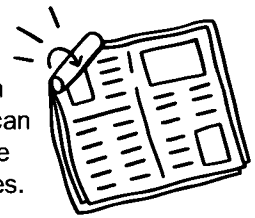
What You Need

- many newspapers
- masking tape
- measuring tape
- markers, glitter, beads, and glue for decorating

Make a Prediction

Predict how many magazines you think your newspaper dome will be able to support.

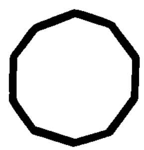
Try It Out



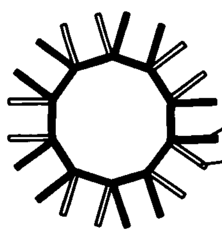
1. Stack three flat sheets of newspaper together. Starting in one corner, roll the sheets up together as tightly as you can to form a tube. When you reach the other corner, tape the tube to keep it from unrolling. Repeat until you have 65 tubes.

2. Now cut down the tubes to make 35 "longs" and 30 "shorts." **Longs:** Cut off both ends of a tube until it is 71 centimeters long. Use this tube as a model to create 34 more longs. Be sure to mark all the longs clearly in some way, such as with colored tape, so you can tell them apart from the shorts. Decorate the tubes if you like. **Shorts:** Cut off both ends of another tube until it is 66 cm long. Use this tube as a model to create 29 more shorts. Decorate the tubes if you like.

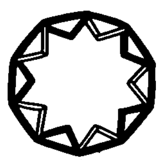
3. First, tape 10 longs together to make the base of the dome.



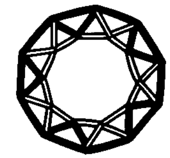
4. Tape a long and a short to each joint. Arrange them so that there are two longs next to each other, followed by two shorts, and so on, as shown.



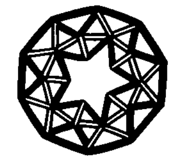
5. Tape the tops of two adjacent shorts together to make a triangle. Tape the next two longs together, and so on all the way around.



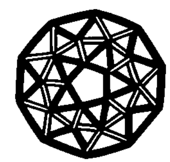
6. Connect the tops of these new triangles with a row of shorts. (The dome will start curving inward.)



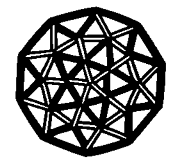
7. At each joint where four shorts come together, tape another short sticking straight up. Connect this short to the joints on either side with longs, forming new triangles.



8. Connect the tops of these new triangles with a row of longs.



9. Finally, add the last five shorts so that they meet at a single point in the center of the dome. (You might need to stand inside the dome to tape them together.) To test your dome's strength, see how many magazines you can load on top.



Explain It

How strong is your dome? Did the results surprise you? Why or why not? What was the hardest part about creating the dome?

Build on It

How could you make your dome stronger without interrupting the space underneath it? Make a prediction and test it.

Newspaper Tower

Educator Ideas

Time
10 minutes

Materials
(per group of two)
- 2 unfolded sheets of newspaper
- ruler
- hand wipes for cleanup

Video Connection
Show "San Gimignano" from **Skyscrapers** (p. 4) to explain the basic forces acting on a tower and the importance of foundations.

Web Connection
pbs.org/buildingbig
Loads Lab

Additional resources are listed on page 38.

Icebreaker

Hold up an **index card** and announce that you want to stand it up on a table. Ask kids if they think you can do this. *(They will probably laugh and say no.)* Stand the card up on one edge so that it falls over. **Ask: Is there anything I can do to make this card stand up?** *(Kids may suggest changing the shape of the paper by folding it, curving it into a column, or tearing the bottom to make "feet.")*

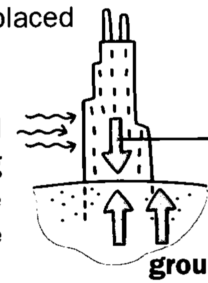
Lead the Activity

- Remind kids to brainstorm all the ways they can alter the paper. Encourage them to think about shapes and stability. Reinforce that looking at what other groups are doing is OK; this is not a competition between groups, but rather a chance to learn from others' discoveries.
- As groups finish and measure their towers, take a group "tour" of the results. **Ask: What forces are affecting these towers?** *(Use one tower as a model to point out that gravity and the dead load of the tower are pushing down, the surface is pushing back up, and small air movements are adding forces from the side.)* **What different solutions did groups come up with to counteract these forces? What is similar about the taller structures?** *(Encourage kids to point out creative uses of shapes, fastening techniques, wide bases, and other solutions to balancing and stiffening their towers.)*

The Big Idea

The strength of a building material can depend on how it is used. Pleating or rolling paper can increase its stiffness. By crumpling, folding, and otherwise reshaping the flimsy flat sheets and by forming a wide base, kids can make the newspaper stand up.

Many forces are at work on towers. Gravity and the dead load of the tower push down, the ground pushes back up, and small air movements push from the side. A foundation distributes the load into the surrounding ground material and can help balance the sideways wind force. The size of the foundation depends on the strength of the supporting ground. A foundation placed in rock can be smaller than a foundation placed in sand or mud.



Build on It

- **Possible outcome:** Kids may use the tape to stiffen the newspaper, particularly at the base, or to hold stable shapes such as triangles or columns together.
- Discuss the difference between dead load (the weight of the tower itself) and live load (the weight of the golf ball).

Make Connections

Physical Education Have kids compare how well they can balance with their feet together and apart. *(Apart is more stable.)* Brainstorm things that have wide bases for stability *(snowshoes, skis, traffic cones).* What spacing between their feet feels most stable? How can kids apply this knowledge in basketball, wrestling, or gymnastics?

Newspaper Tower

Activity Handout

What's the tallest tower you can build using only two sheets of newspaper?

Here's the challenge: getting the newspaper to stand up, without using tape, staples, glue, or other materials. But you can bend, fold, or tear the paper itself.

What You Need

- 2 sheets of newspaper
- ruler

Make a Prediction

Make a prediction about how tall a tower you can build. What is your prediction based on?

Try It Out

1. Now construct your tower. If you think you can make it taller, keep redesigning it until you can't go any higher.
2. When you are finished building, measure the height of your tower.

Explain It

- How did your result compare to your prediction? Give possible reasons for any difference. What limited the height of your tower?
- If you could use one other material to make your tower taller, what would it be? Why?

Build on It

- How much taller can you make the tower if you can add 20 centimeters (about 8 in.) of tape? (You can't tape the tower to the table.) How tall can you make the tower and have it support the weight of a pack of chewing gum?
- How well does your tower withstand environmental forces? Use a fan to imitate wind gusts or shake the table gently to imitate an earthquake. How can you change your design, using 2 sheets of newspaper and 20 cm of tape, to better withstand these forces?

Under Pressure

Educator Ideas

Time
10 minutes to prepare bottle; 30–40 minutes second day

Materials
(per group of 4)
- 2-liter plastic soda bottle
- drinking straw
- acrylic caulk (sold in hardware stores)
- sharp scissors or awl
- long plastic tub if doing activity indoors (groups can share tubs)
- permanent marker
- meterstick
- water

Advance Preparation
Since making the hole in the bottle requires an adult's help, it may be simpler to prepare the bottles ahead of time for the whole group. Let the caulk dry overnight before the activity.

Video Connection
After the activity, show "Dam Basics" from **Dams** (p. 4) to reinforce the link between pressure and dam shape.

Web Connection
pbs.org/buildingbig
Dam Challenge

Additional resources are listed on page 38.

Icebreaker

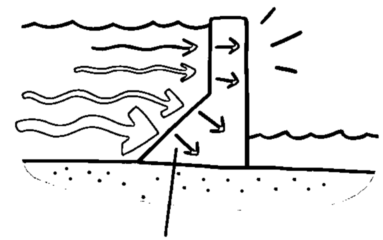
Poke three holes in the side of a **milk carton** and cover them with a single strip of **tape**. Fill the carton with **water**. Hold the carton with one hand and quickly pull off the tape. The water will stream out of each hole with different force. **Ask: Why does the water look different coming out of each hole?** *(Kids may say that the water at the bottom is "stronger.")* Explain that water behind a dam is a live load pressing on the dam. The greater the amount of water built up, the greater the pressure—so the water coming from the bottom hole has more force than the water from the top hole.

Lead the Activity

- This activity is best done outdoors. If you are doing the activity indoors, have kids place the bottles inside a long plastic tub to catch spills.
- A potential source of confusion is that the 20-cm measurement (the full bottle) models the water pressure at the **bottom** of a dam, while the 5-cm measurement (the nearly empty bottle) models the water pressure at the **top** of a dam. At the top of a dam, only a little water is pressing on the dam, as is the case when the bottle is nearly empty. Compare diagrams of a dam and the bottle to ensure that kids understand how the model relates to a real dam.

The Big Idea

Water pressure increases with the depth of the water. In deep water, there is more water "piled up," which causes the pressure to be greater at the bottom than at the surface. A dam's design must enable it to withstand greater pressure at the bottom than at the top. As a result, many dams are built in a triangular shape. The wide bottom withstands the great load of the water deep below the surface, while the top of the dam can be built thinner so as not to use unnecessary costly materials.



Build on It

Water discharging from the bottom of a dam has great force. A structure called a diffuser, sometimes just a mass of large boulders, reduces the force of this discharge. **Possible outcome:** Kids may suggest using multiple spouts or a triangular spout to release the water, or using a diffuser to "break up" the stream of water.

Make Connections

Math Have kids graph their results. Instruct them to put the water depth on the horizontal axis and the distance on the vertical axis.

How great is the water pressure?

The most important load that a dam must be able to support is the water behind it. How much the water pushes on the dam is called **water pressure**. The water pressure pushes on the dam from the side, putting it into **compression**. A dam's shape can help it to withstand this compression.

What You Need

- 2-liter plastic soda bottle
- drinking straw
- acrylic caulk
- sharp scissors or awl
- permanent marker
- meterstick
- water

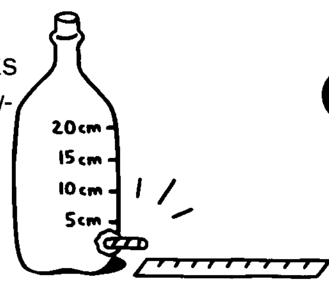
Make a Prediction

Predict how water pressure at the top of a dam compares to the pressure at the bottom of the dam.

Try It Out

1. To make a model dam, ask an adult to drill a small hole near the bottom of the bottle using scissors or an awl. Cut a short piece of straw and insert it in the hole. Squirt caulk all around the straw to make the hole watertight. Let it dry overnight.

2. With a permanent marker, draw marks on the side of the bottle at the following distances up from the straw: 5 centimeters (2 in.), 10 cm (4 in.), 15 cm (6 in.), and 20 cm (8 in.). Label the marks.



3. Place your finger firmly over the end of the straw. Fill the bottle with water.

4. With your finger still over the straw, place the bottle somewhere that can get wet (such as on the ground outside or in a tub). Your partner should place the meterstick under the straw so that one end lines up with the open end of the straw.

5. When you're ready to record your results, remove your finger from the straw. When the water level inside the bottle reaches the 20-cm mark, say, "Twenty." Your partner should record the distance at which the stream of water is hitting the meterstick. Repeat as the water level in the bottle reaches each mark.

Explain It

Was the water pressure greater when the dam was full (20 cm) or nearly empty (5 cm)? How could you tell? How do your results affect how you would design a dam?

Build on It

How could you reduce the force of the water coming out of the bottom of a dam? Make a prediction and test it using your model dam.

Meeting in the Middle

Educator Ideas

Time
15 minutes

Materials
(per group of two)
- large piece of corrugated cardboard or foam-core board
- 2 books or blocks
- 2 ballpoint pens
- paper
- ruler

Video Connection
After the activity, show "Hoosac Tunnel" or "The Chunnel" from **Tunnels** (p. 4) to emphasize the importance of measurement and communication to tunnel building.

Web Connection
pbs.org/buildingbig
Tunnel Challenge

Additional resources are listed on page 38.

Icebreaker

Play a game of "Hot and Cold" to have kids locate an object in the room. Use the game as a starting point for a discussion about the best ways of communicating information and directions, including giving specific measurements.

Lead the Activity

- Kids may ask questions about what they are "supposed to" do in describing the location of their tunnel. Remind them that the goal is to enable their partners to draw a matching tunnel entrance (size and location) on the other side of the cardboard, and part of the challenge is to choose a way of communicating that information as completely as possible.
- Encourage kids to consider different ways of communicating the locations of their tunnel entrances using the materials they have.

The Big Idea

One challenge of tunnel engineering is making precise measurements to ensure that teams building from each end of the tunnel come together in the middle. This activity shows students the importance of choosing which measurements to make and communicating them accurately. Kids may measure points on the circle from different sides of the cardboard, or divide the cardboard into imaginary fractions.

David Macaulay demonstrates surveying equipment in "Hoosac Tunnel" from Tunnels (p. 4).

Build on It

Provide simple building materials, such as drinking straws and paper clips or toothpicks and gumdrops, for kids to use for their designs.

Make Connections

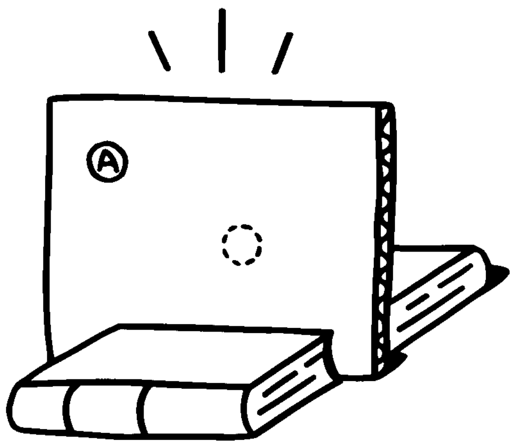
Language Arts Have kids write instructions for a simple task, such as making a peanut-butter sandwich or putting on a jacket. Remind them to use specific language and descriptive nouns, prepositions, and adjectives. Then have them trade instructions and carry them out to the letter to see what details are missing.

How good are your directions?

One major challenge of building a tunnel is making sure that the teams digging from each side meet in the middle. In this activity you will need to describe the location of a tunnel opening on one side of a piece of cardboard to your partner, who will try to recreate it on the other side.

What You Need

- large piece of corrugated cardboard or foam-core board
- 2 books or blocks
- 2 ballpoint pens
- paper
- ruler



Build on It

Sit back to back with a partner so that you are facing away from each other. As you build a simple structure, describe what you are doing. Your partner should follow your directions at the same time. When you are finished, see how closely the two structures match up.

Make a Prediction

Predict how close your partner will be able to get to your tunnel entrance. Why do you think so?

Try It Out

1. Stand the cardboard up on one edge between you and your partner. Place a book on each side of the cardboard to hold it up.
2. Holding onto the cardboard to keep it standing, draw a circle about the size of a penny somewhere on your side of the cardboard. Label the circle A. This is the entrance to Tunnel A. Your partner should draw a circle somewhere on the other side of the cardboard, and label it B (the entrance to Tunnel B).
3. Now describe the location of the Tunnel A entrance to your partner as precisely as you can. Your partner should describe the location of the Tunnel B entrance to you.
4. Based on his or her description, draw the other end of your partner's tunnel on your side of the cardboard. Your partner should do the same.
5. Use the pen to carefully punch a hole where you think your partner's Tunnel B is. Your partner should punch a hole where he or she thinks Tunnel A is. Now turn the cardboard around to see how well you both communicated!

Explain It

How closely did the two ends of each tunnel match up? If one tunnel matched more closely than the other, what do you think accounts for the difference? How is this challenge like the challenge engineers face in digging a long underground tunnel?

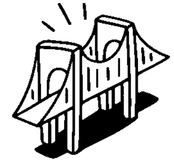
Building Challenges

Educator Ideas

General Tips

- The materials listed for each challenge are suggestions. You can limit or increase the choice of materials depending on what materials are available to you.
- Give kids the challenges ahead of time so they can think about possible solutions before the activity.
- Form groups of 3 or 4 kids for these activities. To ensure that all group members actively participate, assign roles such as "architect," "materials buyer," and "construction foreperson." Have kids switch roles during the activity.
- Incorporate a "design review" stage. Have kids present their plans to another group and trade feedback. Or, you can act as the City Engineer to provide comments and suggestions on each design. The finished projects can serve as outcomes for performance-based assessment.
- Any of these activities can be extended by adding the consideration of environmental loads such as earthquakes (shaking the table) or wind (using a table fan). Have kids test their structures, redesign them, and test them again.

Bridge Challenge

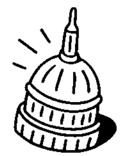


- This activity is a good follow-up to Tug-Push-Twist-O'War, Straw Shapes, Paper Bridge and Suspension Bridge.
- Remind kids that the span must be 45 cm (about 1.5 feet), so the bridge must be longer than that.
- Place the bridge across two desks to test its strength. Use the paper-cup load tester described on page 25 to test each bridge.

Video Connection Afterward, use **Building Small: Bridges** (p. 38) to show how one family met this challenge.

Web Connection Bridge Challenge

Dome Challenge

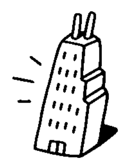


- This activity is a good follow-up to Tug-Push-Twist-O'War and Geodesic Dome.
- Remind kids to consider both geodesic and rib-style domes (as in Human Dome). A rib-style dome can be strengthened with buttresses or a tension ring around the bottom.

Video Connection Afterward, use **Building Small: Domes** (p. 38) to show how two kids built a newspaper dome.

Web Connection Dome Challenge

Skyscraper Challenge



- This activity is a good follow-up to Tug-Push-Twist-O'War, Columns, Newspaper Tower, and Straw Shapes.
- Encourage kids to incorporate cross-bracing in their skyscraper designs.

Video Connection Afterward, use **Building Small: Skyscrapers** (p. 38) to show how one family built newspaper towers.

Web Connection Skyscraper Challenge

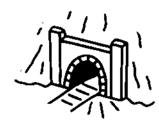
Dam Challenge

- This activity is a good follow-up to Tug-Push-Twist-O'War and Under Pressure.
- **Advance Preparation** Combine water and sand in a trash barrel in a ratio of 1/2 gallon of water to 50 pounds of sand. Scoop wet sand into a sloping heap in one end of a clear plastic storage container. Kids can form a river channel in the wet sand and build a dam at one end of the channel.
- To get kids thinking about how they might use the materials, show "Dam Basics" from **Dams** (p. 4).

Video Connection Afterward, use **Building Small: Dams** (p. 38) to show how two kids met this challenge.

Web Connection Dam Challenge

Tunnel Challenge



- This activity is a good follow-up to Tug-Push-Twist-O'War and Meeting in the Middle.
- Because they cannot use their hands, kids must find a way to dig out the sand and stabilize the sides of the tunnel before laying in the tunnel sections (the toilet-paper tubes). Or, they may model the "shield" method by covering the ends of the tubes with paper and burrowing into the sand.

Video Connection Afterward, use **Building Small: Tunnels** (p. 38) to show how one family met this challenge.

Web Connection Tunnel Challenge

Building Challenges

Activity Handout

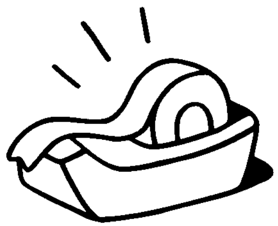
Now that you've been exploring materials, shapes, and forces, it's time to put them together in a structure you design and build.

Choose a challenge, and think BIG!

Bridge Challenge

Design and build the **strongest bridge** you can that spans a distance of 45 centimeters (about 1.5 ft.), using any of these materials:

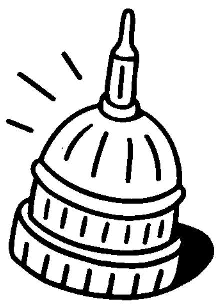
- drinking straws
- paper clips
- newspaper
- tape
- string or yarn



Dome Challenge

Design and build the **widest dome** you can that supports a dictionary, using any of these materials:

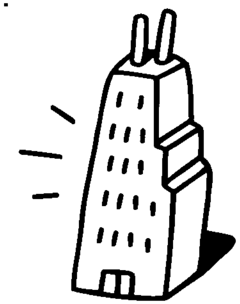
- drinking straws
- pipe cleaners
- tape
- string or yarn



Skyscraper Challenge

Design and build the **tallest skyscraper** you can that supports the load of a golf ball, using any of these materials:

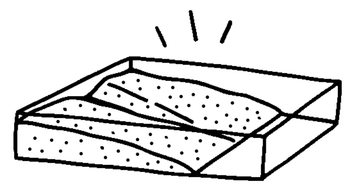
- drinking straws
- paper clips
- newspaper
- tape
- 4 toilet-paper tubes
- salt or sand



Dam Challenge

Design and build a **dam that blocks a river** in a tub of wet sand, using any of these materials:

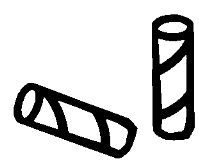
- popsicle sticks
- aquarium gravel
- 1/2 cup of modeling clay



Tunnel Challenge

Design and build a **tunnel through a tub of sand,** without touching the sand with your hands. You can use any of these materials:

- plastic spoon
- 4 toilet-paper tubes
- paper
- tape
- paper cup



Local Wonders

E-mail the American Society of Civil Engineers at buildingbig@asce.org to get your group hooked up with a volunteer civil engineer!

Although your community may not have an Eiffel Tower or a Hoover Dam, it is sure to have many structures with interesting stories. Local Wonders is a fun way for kids to discover the relevance of civil engineering to their daily lives. Over a two- to four-week period, kids work with an engineer to select and investigate an interesting local structure. (See the **Activity Planning Grid** on pages 6–7 for a suggested schedule of activities.) After collecting answers to their questions about the structure, the kids write up their Local Wonder and submit it to the BUILDING BIG Web site (**pbs.org/buildingbig**).

1 Choose your Local Wonder.

Any structure that your group finds significant because of its appearance, uniqueness, or historical or social impact can be a Local Wonder. Consider local bridges, tunnels, skyscrapers or other buildings, domes, dams, and other constructions. Have the kids brainstorm a list, take a bus tour around town for ideas, or collect some photographs to stimulate discussion.

After building Newspaper Towers (p. 28) and talking about structures and foundations, 5th and 6th graders at the Watertown, Massachusetts Boys & Girls Club brainstormed a list of interesting structures in our town: one girl's 10-story apartment building; an elementary school with a recent addition; a new parking garage; and more. We voted and agreed on St. Patrick's, an elaborate church across the street from the clubhouse.

2 Identify questions to guide the investigation.

Have the kids generate a list of questions about the Local Wonder. If they have trouble brainstorming, suggest a few of the following questions to spark ideas:

Engineering focus

- When was it built? How long did construction take?
- Who built it? How many people were needed?
- What is it made of? Why did the builders choose that material?
- Why is it shaped the way it is?
- What holds it up/keeps it from falling down?
- How was it built? Were there any problems during construction? How were they solved?

Social/environmental impact focus

- Why was it built? How did the builders decide where to build it?
- How much did it cost to build? Where did the money come from?
- How is the structure important to the community?
- What did the area look like before it was built? How did it change the area around it?
- Has it had any unexpected effects on the community?

We brainstormed a list of 12 questions, including "How did they decide where to build it?"; "Why did they use arches?"; "What is the meaning of the stained glass?"; and "What's underneath the building?"

3 Investigate the Local Wonder.

You may want to begin with some hands-on activities that explore basic engineering principles such as forces, compression, tension, shape, and torsion. As a group, design a research plan to investigate the Local Wonder.

Your plan might include

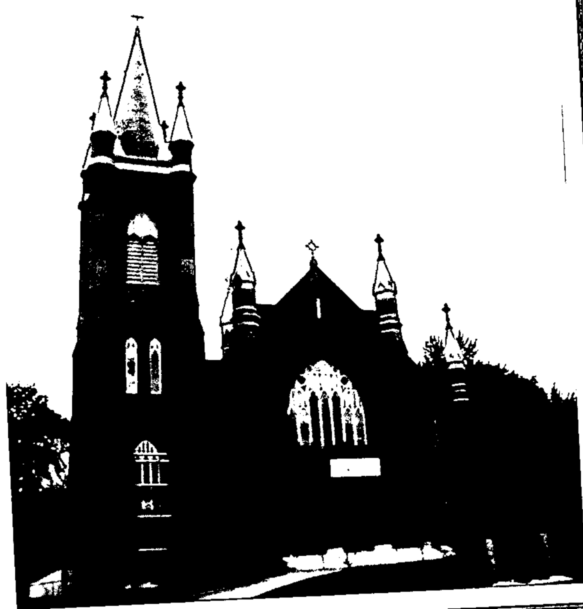
- touring the structure (be sure to take a photo or make some drawings for your Web site submittal);
- researching the structure at a library, historical society, or newspaper;
- interviewing engineers, architects, or contractors who worked on the structure;
- visiting the municipal planning office, engineer, building inspector, or public works department;
- interviewing long-time community residents about their memories about the structure; and
- surveying community members about their current opinions on the structure.

At the library, we found a book about Watertown's history that told the story of when and why St. Patrick's was built. The Historical Society had some photographs of what the church looked like at different times in its history. We visited the Watertown Building Inspector's office and got the building's plans and copies of its renovation permits. Then we took a tour of the building and asked questions. Afterwards, we used all the information to make a timeline about the building's history.

4 Tell us about it.

Once your group completes the investigation, go online to **pbs.org/buildingbig** to submit your Local Wonder. Selected projects will be published on the site as part of the Wonders of the World databank. Look at our example here to see the categories your writeup should include.

With their writeup, kids can submit a photograph or original drawings. Drawings should be in felt-tip marker or ink on 8.5- by 11-inch white, unlined paper. Encourage kids to draw the structure from different perspectives (looking directly at it, looking down on or up at it, imagining what the inside looks like). The Web site has instructions on printing a form to send in with your photos or drawings.



Name of structure St. Patrick's Church

Location Watertown, Massachusetts

Name of group submitting report Watertown Boys & Girls Club

Approximate date structure completed 1901

Approximate size 100-foot tower

Why we chose this Local Wonder It's interesting looking. We wanted to know more about it, like why the builders used arches and what it is made of. It's also near our clubhouse, and someone in our group goes there.

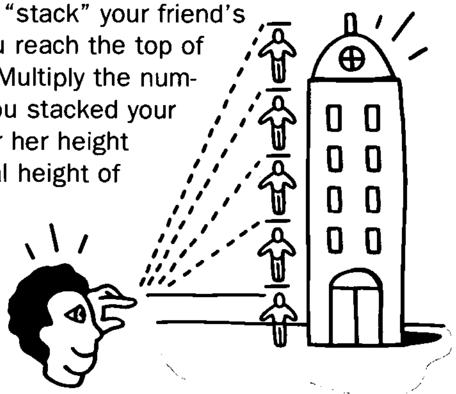
What's important about our Local Wonder People go to services there. It was built after a Catholic church in Waltham burned down and the people needed a new church. Since most of the people lived in Watertown, they decided to build the new church there.

Things we learned about our Local Wonder It is designed in the Romanesque style. The arches hold up the roof and make a big open space inside. Also, the big space echoes so that you wouldn't need a microphone. The stained glass lets in light and was donated by church members (some of the windows have their names on them).

Fun facts about our Local Wonder We estimated that there are 432 little stained glass windows and 240 stairs. We think there are so many stairs because when they first built it, they didn't have elevators, and people wouldn't want to climb really big stairs.

Estimating Size

Here's one way to estimate the size of a large structure. Measure a friend's height. Have your friend stand next to the structure, while you stand a little distance away (across the street, for instance). Close one eye and use your fingers to "stack" your friend's height until you reach the top of the structure. Multiply the number of times you stacked your friend by his or her height to find the total height of the structure.



Check out the Web site for more tips on how to measure the size of different types of structures.

...lditional Resources

To find out more about structures and their builders,

Read

Building Big Companion Book
Macaulay, David. *Building Big.*
Boston: Houghton Mifflin, 2000.
Why this shape and not that? Why steel instead of concrete or stone? Why put it here and not over there? In *Building Big,* the series companion book, David Macaulay gets readers thinking about structures they see and use every day—bridges, tunnels, skyscrapers, domes, and dams. As always, the Caldecott Medal-winning author inspires readers of all ages to look at their world in a new way.
Available in October 2000. Full-color illustrations, 192 pp. $30. ISBN 0-395-96331-1

Brown, David J. *The Random House Book of How Things Were Built.* New York: Random House, 1992.
Detailed, cutaway illustrations tell the stories of great structures throughout history and across the globe. Diagrams explain the basic principles behind these engineering feats.

Darling, David. *Experiment! Spiderwebs to Skyscrapers: The Science of Structures.* New York: Dillon Press, 1991.
Simple explanations, large photographs, and hands-on activities explore foundations, materials, arches, trusses, and structures.

Doherty, Craig, Bruce S. Glassman, Marcia S. Glesko, et al. *Building America Series.* Woodbridge, Connecticut: Blackbirch Press, 1995–1999.
These detailed stories of well-known American engineering wonders, such as the Empire State Building, Grand Coulee Dam, and Houston Astrodome, are good references for research and projects.

Dunn, Andrew. *Structures Series (Bridges; Dams; Skyscrapers; Tunnels).* New York: Thomas Learning, 1993.
Each book explains the importance, design, and construction of one type of structure, using photographs and examples from all over the world. Hands-on activities demonstrate basic engineering principles.

Kaner, Etta. *Bridges.* Toronto: Kids Can Press, 1997.
Through a combination of illustrations, photographs, and simple hands-on activities, this book explains the physics behind a variety of bridge designs.

Lafferty, Peter. *Eyewitness Books: Force & Motion.* New York: DK Publishing, 2000.
This guide integrates clearly written text with colorful visuals, including photographs, charts, illustrations, and models, to introduce the basic science of forces and motion.

Morgan, Sally, and Adrian Morgan. *Designs in Science: Structures.* New York: Facts on File, 1993.
Colorful photographs and interesting facts and figures compare structures found in nature with those built by people. Diagrams and hands-on activities explain basic physical science principles such as forces and load.

Salariya, David, and Joanne Jessop. *The X-Ray Picture Book of Big Buildings of the Modern World.* New York: Franklin Watts, 1994.
Detailed cutaway illustrations highlight interesting features of famous skyscrapers, cathedrals, and monuments from around the globe.

Salvadori, Mario. *The Art of Construction.* Chicago: Chicago Review Press, 1990.
The friendly writing style, drawings, and frequent examples using household items make this classic presentation of the physical science of structures accessible for kids when presented in excerpts.

Visit

Building Big Web Site
pbs.org/buildingbig
The series Web site features interactive activities and building challenges, a searchable databank of engineering wonders, interviews with engineers, and more.

American Society of Civil Engineers
asce.org
The official site of the American Society of Civil Engineers provides information on all branches of civil engineering.

Boston's Big Dig
bigdig.com
This site describes the challenges and methods of large-scale urban civil engineering, including the construction of tunnels, bridges, and roads, and highlights the project's environmental and social impact.

Engineering Simulation
usa.siemens.com/buildingbig
Kids can give Siemens engineers a hand designing their own airports using this online building simulation exercise.

Hoover Dam
hooverdam.com
The official Hoover Dam Visitor Center site provides information on the dam, plus materials for educators.

NOVA Online: Super Bridge
pbs.org/nova/bridge
Clear text and diagrams compare various bridge designs. An interactive activity challenges visitors to choose the best bridge design for specific sites.

Online Ethics Center for Engineering & Science
onlineethics.org
This site profiles a number of case studies in engineering ethics, including a thorough presentation of the Citicorp Tower crisis featured in **Skyscrapers** and **Thinking Big.**

Rice University Bridges Project
civil.rice.edu/scripts/bridges
This site features a searchable databank of bridge facts, figures, and photographs; a historical overview of bridge design; and an interactive building simulation.

Watch

Building Big with David Macaulay Boxed Set
Award-winning author-illustrator—and captivating storyteller—David Macaulay goes to extremes with five adventures that explore the greatest engineering wonders of the world: bridges, dams, domes, tunnels, and skyscrapers. The series introduces the courageous creators and builders and reveals the triumphs and struggles behind these breathtaking structures. Spectacular film footage, dramatic recreations, and Macaulay's uniquely illuminating illustrations excite, explain, and entertain in a big way.
5 hours • $69.95
Individual videos also available • **1 hour • $19.95 each**

Thinking Big and Building Small
Ideally suited for educators, **Thinking Big** explores the process of engineering design through interviews with engineers and middle-school kids and one skyscraper's dramatic story. The video also contains **Building Small,** five hands-on building activities hosted by two kids from the hit PBS show ZOOM™.
1 hour • $19.95

To place an order for any of these videos, or to request a free catalog, please contact WGBH Boston Video at 800-949-8670.

N...ional Content Standards

BUILDING BIG and the activities in this guide address the following national content standards for science, math, and technology.

National Science Education Standards

Grades 5–8

Content Standard A Science As Inquiry

Abilities necessary to do scientific inquiry

Identify questions that can be answered through scientific investigations.
Design and conduct a scientific investigation.
Use appropriate tools and techniques to gather, analyze, and interpret data.
Develop descriptions, explanations, predictions, and models using evidence.
Think critically and logically to make the relationships between evidence and explanations.
Recognize and analyze alternative explanations and predictions.
Communicate scientific procedures and explanations.
Use mathematics in all aspects of scientific inquiry.

Understandings about scientific inquiry

Content Standard B Physical Science

Motions and Forces

Content Standard E Science and Technology

Abilities of technological design

Identify appropriate problems for technological design.
Design a solution or product.
Implement a proposed design.
Evaluate completed technological designs or products.
Communicate the process of technological design.

Understandings about technological design

Content Standard F Science in Personal and Social Perspectives

Natural Hazards
Risks and Benefits
Science and Technology in Society

Content Standard G History and Nature of Science

Science As a Human Endeavor
History of Science

82

National Council of Teachers of Mathematics (NCTM) Standards

Expectations for Grades 6–8

Geometry

- Recognize and apply geometric ideas and relationships in areas outside the mathematics classroom, such as art, science, and everyday life

Measurement

- Select and use appropriate units and tools, depending on degree of accuracy required, to find measurements for real-world problems

Problem-solving

- Solve problems that arise in mathematics and in other contexts
- Apply and adapt a variety of appropriate strategies to solve problems

Connections

- Recognize and apply mathematics in contexts outside of mathematics

Representations

- Create and use representations to organize, record, and communicate mathematical ideas
- Use representations to model and interpret physical, social, and mathematical phenomena

International Technology Education Association Technology Content Standards

The Nature of Technology

Standard 1: Students will develop an understanding of the characteristics and scope of technology.
Standard 2: Students will develop an understanding of the core concepts of technology.
Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

Technology and Society

Standard 4: Students will develop an understanding of the cultural, social, economic, and political effects of technology.
Standard 5: Students will develop an understanding of the effects of technology on the environment.
Standard 6: Students will develop an understanding of the role of society in the development and use of technology.
Standard 7: Students will develop an understanding of the influence of technology on history.

Design

Standard 9: Students will develop an understanding of engineering design.
Standard 10: Students will develop an understanding of the role of troubleshooting , research and development, invention and innovation, and experimentation in problem-solving.

Abilities of a Technological World

Standard 11: Students will develop abilities to apply the design process.

The Designed World

Standard 20: Students will develop an understanding of and be able to select and use construction technologies.

83

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Front cover, inside front and back cover: © 2000 David Macaulay
All others: Stephen Schudlich

Photography
Front and back covers, pages 28 (bottom), 40: Jeffrey Dunn/ © 2000 WGBH
Pages 3, 4, 32 (bottom): Production Group, Inc.
Pages 14, 16, 18, 20, 22, 24, 26, 28 (top), 30, 32 (top), 34: Julie DiAngelis/ © 2000 WGBH
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Special thanks to

K'NEX™ Industries
ASCE Offices of Communications and State Public Affairs
Benn Sherman, P.E., BSC Group
Ernie Thebado and the Watertown, Massachusetts Boys & Girls Club
Philadelphia H.O.M.E.S. 4-H Club

BUILDING BIG is a co-production of WGBH Boston Science Unit and Production Group, Inc. Major funding is provided by the National Science Foundation.

National Science Foundation

Additional funding is provided by the National Endowment for the Humanities, The Arthur Vining Davis Foundations, the Corporation for Public Broadcasting, and public television viewers. National sponsorship is provided by the American Society of Civil Engineers and Siemens.

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Being a sponsor of *Building Big* is a natural fit for Siemens. As a global player in the electronics and electrical engineering markets, our company is involved in many of the world's largest building projects. In addition, we have a history as a strong supporter of education. Our commitment to education is demonstrated through many initiatives, including the establishment of the Siemens Foundation and a variety of successful school-to-work and apprenticeship programs in the United States.

The Siemens Foundation is dedicated to providing scholarships and access to higher education for gifted science, math, and technology students across the country. The foundation's programs include the Siemens Westinghouse Science and Technology Competition and the Siemens Awards for Advanced Placement. Both of these programs are dedicated to recognizing and rewarding today's outstanding student talent, as well as the teachers and schools that encourage them. *(Teachers interested in learning more about these scholarship programs should visit the foundation's Web site at www.siemens-foundation.org)* The foundation embodies Siemens' contributions to education and research and a 150-year history of encouraging and supporting young talent. These efforts help ensure tomorrow's pool of highly trained, highly skilled scientists and engineers who will be ready to meet the competitive demands of a global economy.

Siemens and its family of companies in the United States are proud to sponsor *Building Big*, which we're sure you and your students will find exciting, inspiring, and enriching.

Gerhard Schulmeyer

Gerhard Schulmeyer
President and CEO
Siemens Corporation

Dear Educator,

Soaring skyscrapers…massive dams…bridges that reach the horizon… Who dreams these thrilling and wondrous things and then makes them real?

The 123,000 civil engineers who together make up the American Society of Civil Engineers.

Most civil engineers discovered our passion for engineering as kids. Our fascination with incredible feats of engineering sparked an interest in understanding the scientific principles that make them possible, and it was teachers who nurtured our interest in math and science.

ASCE is delighted to help share the excitement of engineering through our sponsorship of *Building Big* and eager to join educators in inspiring young people to use science and creativity to help build a better world.

James E. Davis, P.E., F.ASCE
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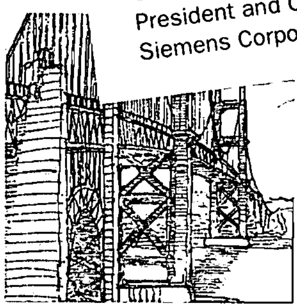

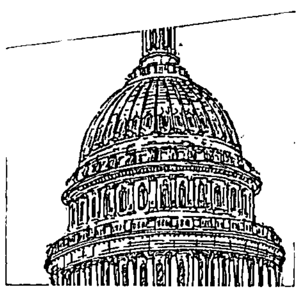

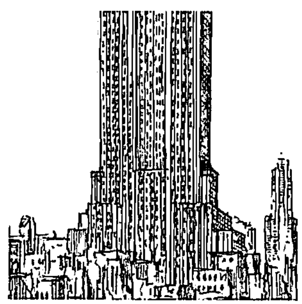

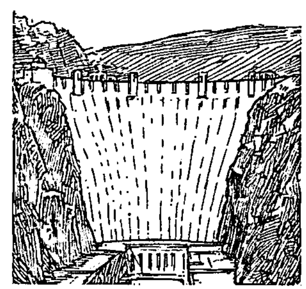

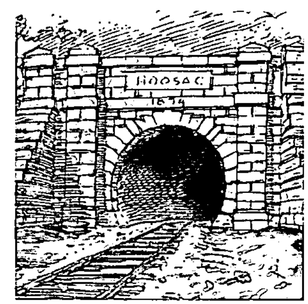

WGBH Educational Foundation
Building Big Activity Guide
Educational Print and Outreach
125 Western Avenue
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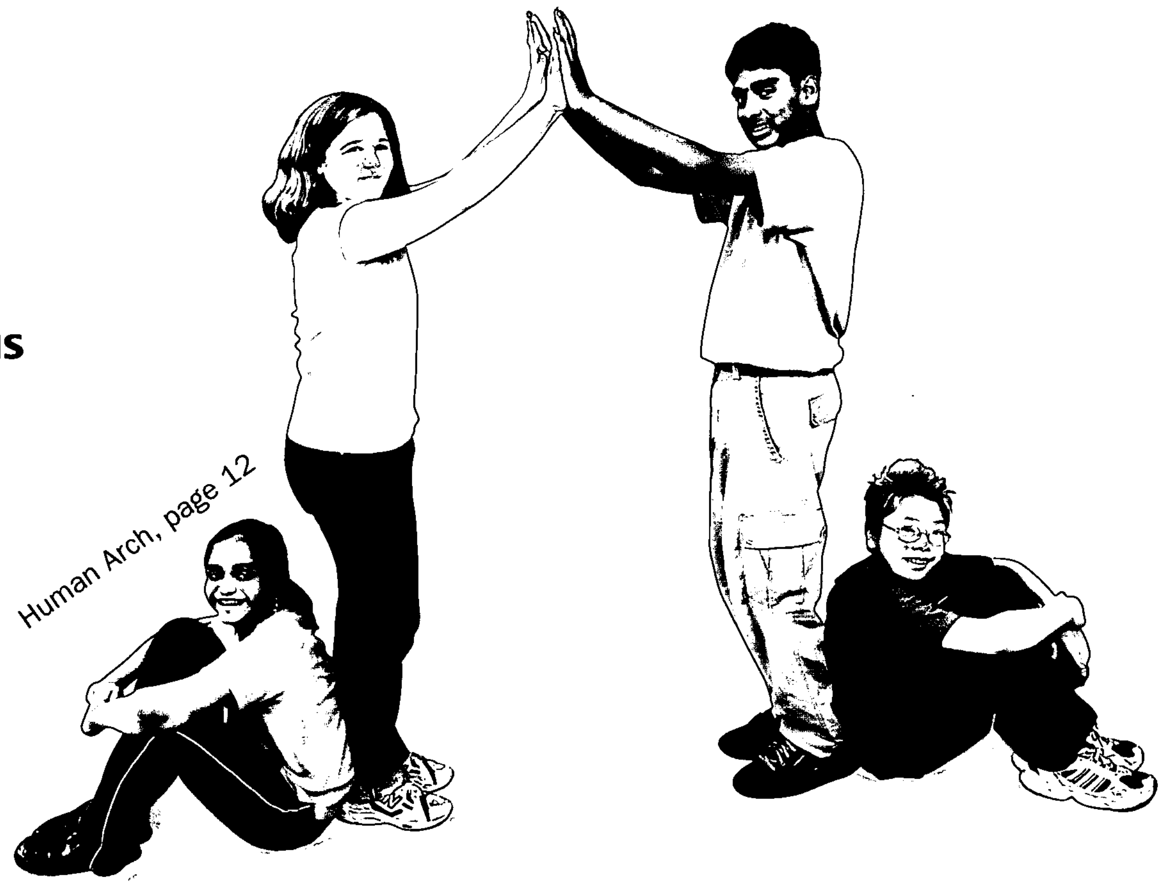

Human Arch, page 12

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